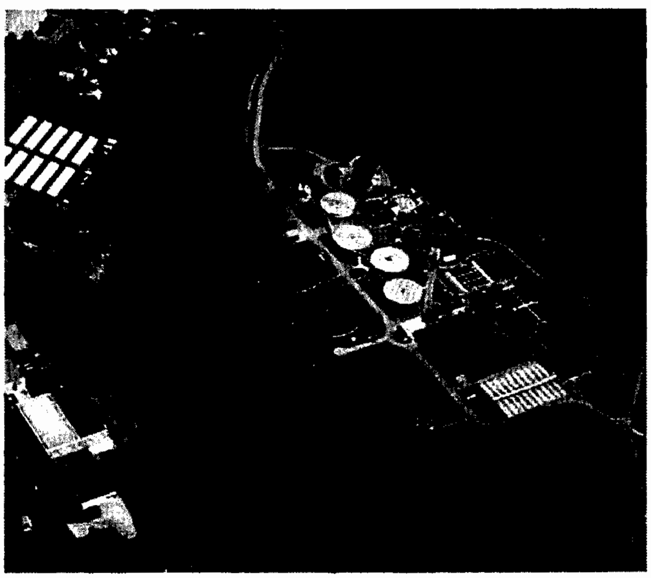
CITY OF READING

IMPROVEMENTS
TO THE
FRITZ ISLAND WASTEWATER TREATMENT PLANT

SUPPLEMENTAL REPORT TO
FINAL ACT 537 SPECIAL STUDY



RK&K

JANUARY 31, 2014

RK&K

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LETTER OF TRANSMITTAL

Sheet: 1 of 1 Total Pages: 1
Date: January 31, 2014
Job No.: 213-054
Project: Improvements to the Fritz Island WWTP

To: NPDES Enforcement Branch (3WP42)
USEPA, Region 3
1650 Arch Street
Philadelphia, PA 19103

Attention: Ms. Lisa Trakis

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Ms. Trakis – copy also provided previously by email

Copy: 213-054 File
cc: Scott Perry, City of Reading

Rummel, Klepper & Kahl, LLP

Signature: ____________________
Del Becker, PE
Project Manager

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CITY OF READING, PENNSYLVANIA

815 WASHINGTON STREET
READING, PA 19601-3690
(610) 655-6204

Pennsylvania Department of Environmental Protection
Reading District Office
Water Management Program
1005 Cross Roads Boulevard
Reading, PA 19605
Attention: Ms. Renae Wood

Subject: Supplemental Report to Final Act 537 Special Study

Dear Ms. Wood:

Enclosed are two copies of the Supplemental Report prepared for the City of Reading's (City) by RK&K, the City's design engineer for the Fritz Island Wastewater Treatment Plant (WWTP) upgrade project. An electronic copy can be provided for your use.

The Supplemental Report documents a change in design basis and a process re-evaluation that led to the selection of the activated sludge process in lieu of the hybrid trickling filter / activated sludge process and other processes for the Fritz Island WWTP upgrade project. In 2012, the Final Act 537 Special Study provided recommended improvements for the liquid, solids, and non-process systems at the WWTP.

The selected hybrid liquid process alternative was termed H-2 and included rehabilitation of the trickling filters (TF), including media replacement, followed by treatment with a new activated sludge system to meet pending effluent ammonia limits, and with modifications, to meet anticipated future year-round effluent nitrogen and phosphorus limits.

During the preliminary design phase in Summer/Fall 2013 of the liquid process for Alternative H-2, two issues became evident:

- Additional suspended growth reactor volume would be required to preclude the use of an excessively high mixed liquor suspended solids concentration.
- The cost for the facilities associated with the TFs would be significantly greater than the cost of additional suspended growth reactors that would accomplish equivalent treatment if the TFs were eliminated (Alternative AS-1 in the Act 537 Special Study).

As a result of these issues and other design basis modifications, the City's design engineer and Project Manager/Construction Manager team developed a revised alternative H-2R. For evaluation purposes, a revised alternative AS-1R was also developed. A comparative technical and present worth cost analyses of the revised alternatives demonstrated that the use of a revised all-suspended growth system (Alternative AS-1R) would result in approximately $21 million in construction cost savings and $18 million in present worth savings compared to the revised hybrid system (Alternative H-2R) and also offered several technical and operational advantages.

The City agrees with the findings of the Supplemental Report. After consultation with the Department's Southcentral Regional Office, the preliminary design of an all-suspended growth system was initiated in lieu of the hybrid system H-2, and this Supplemental Report has been prepared and is presented concurrently with the revised design of the treatment facilities.

CITY OF READING, PENNSYLVANIA

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This Supplemental Report does not supersede the Final Act 537 Special Study, but documents the deviations and modifications from the design basis presented in the Final Act 537 Special Study. The modifications from the Final Act 537 Special Study are limited to the liquid process alternative and associated design basis. There are no modifications to the recommendations for the solids or non-process systems and other section of the Final Act 537 Special Study.

This report is presented for the Department's review and documents the City's revised technical approach to implementing improvements to the Fritz Island WWTP. Should you have any questions, please call me or Mr. Scott Perry at (610) 655-6587.

Sincerely,

Ralph E. Johnson

Ralph E. Johnson, Wastewater Manager

cc: Ms. Lisa Trakis, USEPA
Mr. Shawn Arbaugh, PADEP
Mr. Timothy Wagner, PADEP

CITY OF READING

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SUPPLEMENTAL REPORT TO
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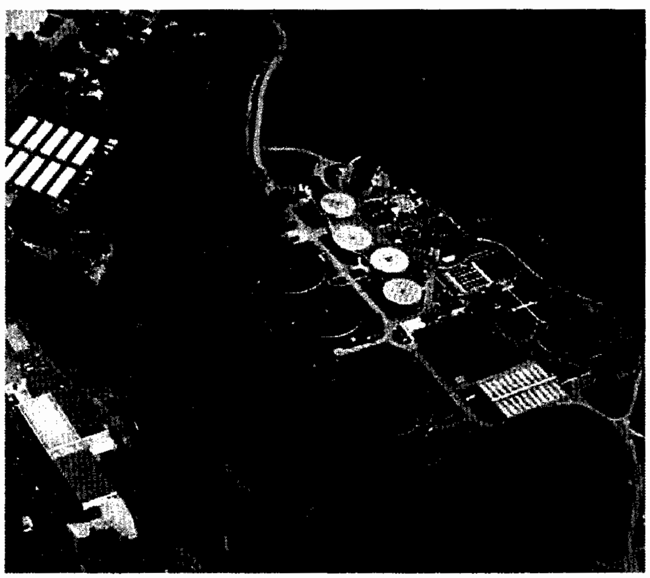

RK&K

JANUARY 31, 2014

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EXECUTIVE SUMMARY

This Supplemental Report documents the change in design basis and process re-evaluation that led to the selection of the activated sludge process in lieu of the hybrid trickling filter/ activated sludge process and other processes for the Fritz Island Wastewater Treatment Plant (WWTP) upgrade project. In 2012, the Act 537 Special Study provided recommended improvements for the liquid, solids, and non-process systems at the WWTP. The selected hybrid liquid process alternative was termed H-2 and included rehabilitation of the trickling filters (TF), including media replacement, followed by treatment with a new activated sludge system to meet pending effluent ammonia limits, and with modifications, to meet anticipated future year-round effluent nitrogen and phosphorus limits. During the preliminary design phase in Summer/Fall 2013 of the liquid process for Alternative H-2, two issues became evident:

- Additional suspended growth reactor volume would be required to preclude the use of an excessively high mixed liquor suspended solids concentration.
- The cost for the facilities associated with the TFs would be significantly greater than the cost of additional suspended growth reactors that would accomplish equivalent treatment if the TFs were eliminated (Alternative AS-1 in the Act 537 Special Study).

As a result of these issues and other design basis modifications, RK&K and the City's Project Manager/Construction Manager team developed a revised alternative H-2R. For evaluation purposes, a revised alternative AS-1R was also developed. RK&K's comparative technical and present worth cost analyses of the revised alternatives demonstrated that the use of a revised all-suspended growth system (Alternative AS-1R) would result in approximately $21 million in construction cost savings and $18 million in present worth savings compared to the revised hybrid system (Alternative H-2R) and offered several technical advantages. The City concurred with RK&K's findings and indicated the preliminary design of an all-suspended growth system should be initiated in lieu of the hybrid system and this Supplemental Report should be prepared concurrently with the design of the treatment facilities.

This Supplemental Report does not supersede the Act 537 Special Study, but documents the deviations and modifications from the design basis presented in the Act 537 Special Study. The modifications from the Act 537 Special Study are limited to the liquid process alternative and associated design basis and there are no modifications herein to the recommendations for the solids or non-process systems.

To meet the impending effluent ammonia limits and other provisions of the NPDES permit, Alternative AS-1R will consist of the following facilities for the initial conditions:

- Screening and grit removal for the vast majority of the flow, ?
- Primary clarifiers,
- Suspended growth reactors with a total volume of 7.5 million gallons (MG) in a step feed configuration,
- Four 160 ft- diameter secondary clarifiers with return and waste activated sludge pumping,
- Chlorination and dechlorination,

- Post aeration, and
- Surface water discharge to the Schuylkill River.

To meet anticipated future nutrient removal limits, future modifications will consist of the following facilities:

- The addition of 7.5 MG suspended growth reactor volume with conversion to the Five-Stage Bardenpho process in a plug flow configuration with a nitrate recycle stream
- Addition of chemical feed facilities for phosphorus precipitation, and
- Addition of supplemental carbon feed facilities for nitrogen removal.

SECTION 1. BACKGROUND

The Fritz Island Wastewater Treatment Plant (WWTP) is owned and operated by the City of Reading, Pennsylvania (City). The facility discharges to the Schuylkill River under NPDES Permit No. 974763. Beginning in 2003, the City has worked with the United States Department of Justice (USDoJ) as well as United States Environmental Protection Agency (USEPA) and the Pennsylvania Department of Environmental Protection (PADEP) to discuss Clean Water Act issues and associated forthcoming lawsuit. This suit was settled and culminated in a Consent Decree which was executed in December 2004 and signed by the judge with November 7, 2005 as the Entry Date. Amongst its various requirements, the Consent Decree detailed numerous interim measures that involve developing, implementing, and maintaining various management systems designed to improve plant operations and maintenance with the ultimate goal of permit compliance.

As part of complying with the Consent Decree, several reports were developed for the City. In February 2006, the City submitted the *"Existing Process Evaluation and Treatment Alternatives Report"* (2006 Report) to the USDoJ. The 2006 report was based on a WWTP capacity of 10 million gallons per day (mgd). Due to experiencing higher flows, the City of Reading retained the services of Hazen and Sawyer, to re-evaluate the hydraulics, liquid process and solids process of the Fritz Island WWTP to determine the capacity of the existing treatment process and produce a new *"Existing Plant Process Evaluation Report"* (2010 Phase I Report). Subsequently, Hazen and Sawyer also prepared Phase II and Phase III Reports. The Phase II Report was titled the *"Evaluation of Treatment Alternatives"* and provided an evaluation of several different liquids and solids process improvement alternatives under existing and future flow/limits scenarios. The Phase III Report was titled the "Capital Improvements Plan" and was prepared in 2011. The Phase III Report provided estimated capital costs for the implementation of the recommended treatment alternatives at the WWTP. The Phase I-III reports were prepared on the basis of a 28.5 mgd design capacity.

Subsequent to the preparation of the Phase I-III reports, it was determined that the plant may not reach the 28.5 mgd design capacity within a 20-year planning period. Consequently, in August 2012, the City retained the services of the SSM Group, Inc. (SSM) to prepare the *"Components of an Act 537 Special Study"* (Act 537 Special Study) in order to evaluate the WWTP service area and to determine the growth potential and projected WWTP service needs for the City and each of the contributing municipalities. The primary purpose of the Act 537 Special Study was to identify the design flow and loading rates for the selected WWTP rehabilitation and upgrade alternatives.

The Act 537 Special Study included evaluating the following:

- Planning and growth potential for the City and the other townships that are in the WWTP service area
- Determination that the WWTP capacity would be 20.5 MGD by Year 2035
- Determination of influent design flows and loads

- Evaluation of the existing conditions of the WWTP, including the hydraulic and treatment capacity of each unit process
- Development of treatment alternatives to meet projected capacity based on influent wastewater characteristics, waste load projections, current permit limits and future regulatory requirements. Both liquid and solids treatment alternatives were developed. Alternatives were based on meeting impending permit limits (nitrification only to meet a year-round ammonia limit) and anticipated future year-round nutrient removal limits summarized in Table 5-7 of the Act 537 Special Study which is included in the Appendix.

The liquid biological treatment alternatives that were evaluated were:

1. Alternative FF-1: Rehabilitation of the existing TFs and replacing the rock media and existing synthetic media with new structured media followed by treatment with a new fixed bed biofilm reactor.
2. Alternative H-1: Rehabilitation of the TFs, with diversion of a portion of the primary effluent flow directed to the TFs and the remaining portion to new activated sludge reactors. This alternative did not include TF media replacement.
3. Alternative H-2: Rehabilitation of three TFs, including media replacement followed by treatment with new activated sludge reactors.
4. Alternative AS-1: Treatment with new activated sludge reactors and abandonment of the existing TF system.

The solids treatment alternatives that were evaluated were:

1. Continue the existing process of co-thickening in the same configuration as the current operations.
2. Separate sludge thickening for secondary sludge only to reduce the loading rates to the gravity belt thickeners.
3. Evaluate the use of centrifuges in lieu of the existing or new belt filter presses for dewatering.

The alternatives were evaluated on the basis of lowest present worth cost and the following factors:

- Reuse of existing infrastructure
- Potential to eliminate intermediate pumping
- Expandability
- Reliability of the nitrification process
- Relative operational cost

The Act 537 Special Study recommended the use of the following:

- Liquid System Alternative H-2: Rehabilitation of three TFs, including media replacement followed by treatment with new activated sludge reactors
- Solids System Alternative 1: Co-thickening and use of new centrifuges for dewatering

The Act 537 Special Study included a comprehensive Capital Improvements Plan and construction cost estimates for both the above alternatives and for non-process related improvements at the WWTP. The estimated construction costs were:

- Liquids Process = $42.66 million
- Solids Process = $27.61 million
- Non-Process Improvements = $31.33 million

The City requested modification of the Consent Decree on August 24, 2012. On September 14, 2012, the modification was approved by the USDoJ on the condition that construction of the improvements be completed no later than February 28, 2018.

In Spring 2013, the City retained the services of RK&K to complete the final design of the recommended improvements. The design kick-off was May 30, 2013 and RK&K completed the following design milestones related to the treatment system through Fall 2013:

- Completion of Wastewater Characterization/Nitrification Kinetics Study; report dated August 30, 2013 (completed by EnviroSim Associates, Ltd. (EnviroSim) as a subconsultant to RK&K, included in the Appendix)
- Draft Liquid Process Technical Memorandum (TM) submitted August 16, 2013; final submitted October 4, 2013
- Draft Solids Process TM submitted August 16, 2013; final submitted October 17, 2013
- Preparation of Basis of Design Report (BODR), also considered the 30% design (to be submitted in February 2014)

The City received NPDES Permit No. PA0026549 dated November 25, 2013. The impending limits summarized in PART A Effluent Limitations, Monitoring, Recordkeeping and Reporting Requirements, included in the Appendix, reflect slightly greater allowable effluent ammonia concentrations compared to those shown in Table 5-7 in the Act 537 Special Study.

As the design progressed after the completion of the Liquid Process TM, it became apparent that the sizing for the selected liquid process alternative needed to increase to accommodate additional mixed liquor due to findings of the Wastewater Characterization/Nitrification Kinetics Study and due to refinements in the projected performance of the upgraded TFs. During the period from October through December 2013, RK&K worked with the City and their Project Manager/Construction Manager (PM/CM) Team to revise the design basis of Alternative H-2. As an outcome of that process, the original

AS-1 Alternative was re-evaluated and determined to be the recommended alternative for the revised analysis.

This Supplemental Report was prepared to document the changes in design basis and process re-evaluation that led to the selection of the revised process alternative. This Supplemental Report does not supersede the Act 537 Special Study, but documents the deviations and modifications from the design basis presented in the Act 537 Special Study.

SECTION 2. BIOLOGICAL TREATMENT SYSTEM PROCESS ANALYSIS - SUMMARY

As indicated above, the Act 537 Special Study recommended the use of a hybrid trickling filter/activated sludge process known as Alternative H-2. This alternative was determined during the Act 537 Special Study to be less costly than an all activated sludge process, known as Alternative AS-1.

Alternative H-2 consisted of the following facilities for initial conditions:

- Screening and grit removal for the vast majority of the flow,
- Primary clarifiers,
- Trickling filters
- Intermediate and recycle pumping,
- Suspended growth reactors,
- Secondary clarifiers with return and waste activated sludge pumping,
- Chlorination and dechlorination,
- Post aeration, and
- Surface water discharge to the Schuylkill River.

Also as indicated above, to meet anticipated future nutrient removal limits, the planned future modifications for H-2 would consist of the following facilities:

- The addition of suspended growth reactor volume with conversion to the Five-Stage Bardenpho process in a plug flow configuration with a nitrate recycle stream
- An optional primary clarifier effluent feed directly to the suspended growth reactor
- Addition of chemical feed facilities for phosphorus precipitation, and
- Addition of supplemental carbon feed facilities for nitrogen removal

A schematic of the proposed H-2 process was provided in Figures 8-1 (initial conditions) and 8-2 (future conditions) of the Act 537 Special Study, both of which are included in the Appendix. The layout of the liquid treatment process is shown in Figure 8-4 of the Act 537 Special Study and is also included in the Appendix.

During the development of the liquid process design for Alternative H-2 two issues became evident to RK&K subsequent to the submission of the Liquid TM in October 2013:

- A significantly greater mass of mixed liquor in the suspended growth reactors would be required to accomplish the treatment objectives in comparison to the mass that was contemplated in the Act 537 Special Study for both the initial and the future conditions for Alternative H-2. The practical consequence of this fact is that additional suspended growth reactor volume would be required to preclude the use of an excessively high mixed liquor suspended solids concentration.
- The cost for the facilities associated with using the TFs (i.e., the Trickling Filter Distribution Structure, the TF upgrades, replacing the TF influent/effluent piping, the Intermediate/Recycle

PS and snail removal systems) would be significantly greater than the cost of additional suspended growth reactors that would accomplish equivalent treatment if the TFs were eliminated (Alternative AS-1 in the Act 537 Special Study).

As a result of these issues and other design basis modifications (discussed further below), RK&K and the PM/CM team developed a revised alternative H-2R. For evaluation purposes, a revised alternative AS-1R was also subsequently developed. RK&K's comparative technical and present worth cost analyses of the revised alternatives demonstrated that the use of a revised all-suspended growth system (Alternative AS-1R) would be less costly compared to the revised hybrid system (Alternative H-2R) and offered several technical advantages. At the December 17, 2013 progress meeting, the City concurred with RK&K's findings and indicated the preliminary design of an all-suspended growth system should be initiated in lieu of the hybrid system. The revised liquid treatment process was designated as Alternative AS-1R and will consist of the following facilities for the initial conditions:

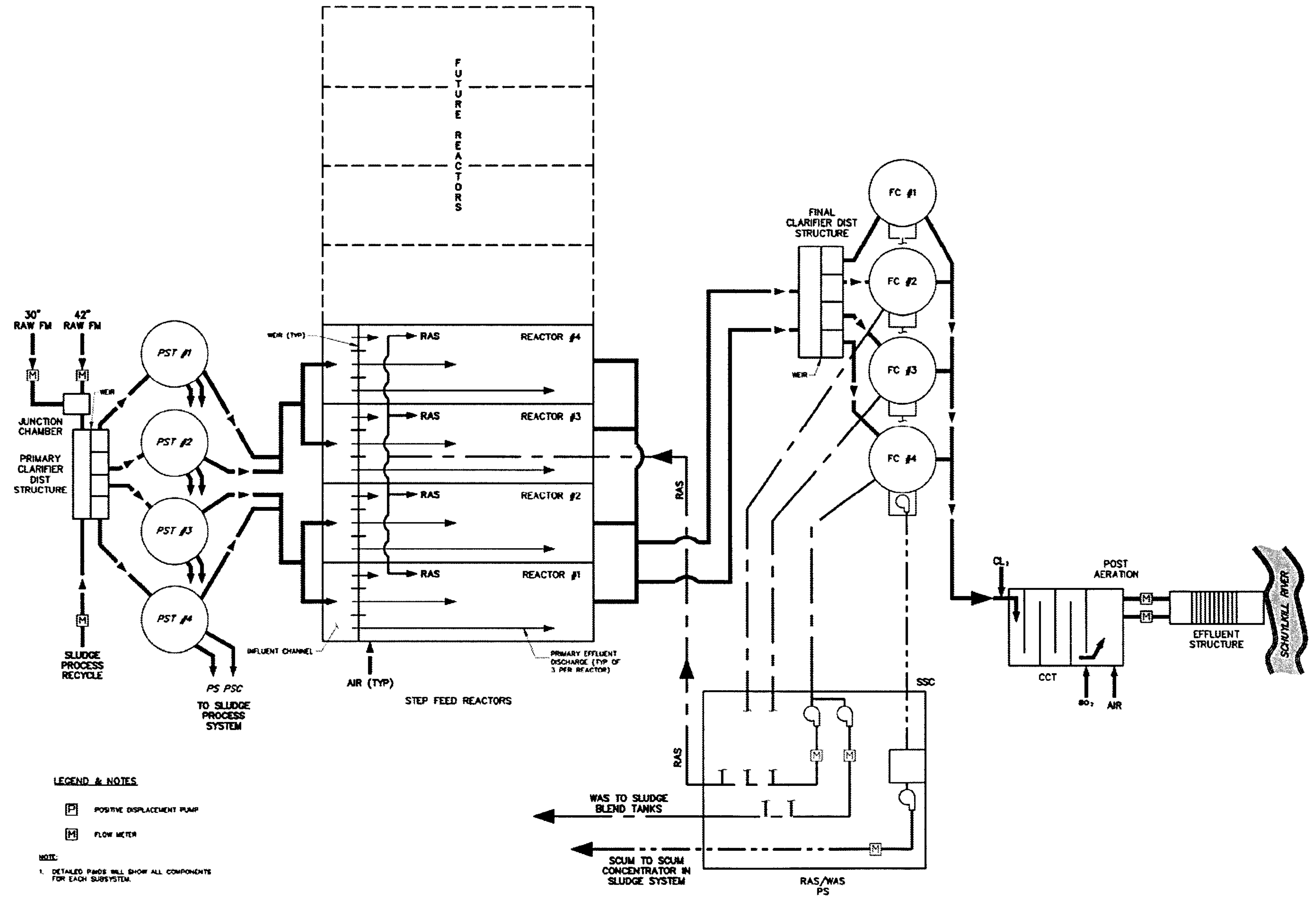
- Screening and grit removal for the vast majority of the flow,
- Primary clarifiers,
- Suspended growth reactors with a total volume of 7.5 MG in a step feed configuration,
- Four 160-ft. diameter secondary clarifiers with return and waste activated sludge pumping,
- Chlorination and dechlorination,
- Post aeration, and
- Surface water discharge to the Schuylkill River.

A schematic of the proposed AS-1R process is included at the end of this section (Figure 1).

To meet anticipated future nutrient removal limits, future modifications will consist of the following facilities:

- The addition of 7.5 MG of suspended growth reactor volume with conversion to the Five-Stage Bardenpho process in a plug flow configuration with a nitrate recycle stream
- Addition of chemical feed facilities for phosphorus precipitation, and
- Addition of supplemental carbon feed facilities for nitrogen removal

The technical and economic analyses supporting the decision to implement Alternative AS-1R is described herein and summarized in the separate BODR being prepared for February 2014 submission to the City.



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NO.	DESCRIPTION	BY	DATE
	REVISIONS		

CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP
BERKS COUNTY PENNSYLVANIA

LIQUID PROCESS OVERVIEW

ENGINEER	DESIGNED BY
DPB	MAS
DRAWN BY	DATE
JAB	12/2013

PROJECT NUMBER
213-054

DRAWING NUMBER
FIGURE 1

SHEET NO. OF X

SECTION 3. MODIFICATIONS TO DESIGN BASIS

During the Summer and Fall 2013, the preliminary design developed through the completion of the Liquid TM and through completion of the Wastewater Characterization/Nitrification Kinetics Study. The Liquid TM included an evaluation of plant data to determine facility design criteria. Plant data for the period 2010- 2013 were evaluated to determine existing, maximum month and peak hourly flow rates, and average, maximum month and peak day influent concentrations. The design criteria information was used to develop mass balances, sizing and to obtain vendor recommendations. The Wastewater Characterization/ Nitrification Kinetics Study was performed by EnviroSim and resulted in a design nitrification rate and detailed wastewater characterization to be used for Biowin simulation modeling and sizing.

As the preliminary design developed for Alternative H-2, several modifications were required to the design basis due to various factors as detailed below. There were also refinements in cost information received as the design evolved. As the design progressed, it became apparent that H-2 may not be the lowest cost alternative based on the revised design conditions. On that basis, the changes to the design basis were also re-evaluated for AS-1, to determine which alternative was most cost effective based on up-to- date design modifications. The following discussion provides:

1. The original design basis of each alternative as proposed in the Act 537 Special Study
2. Modifications to the design criteria with an explanation of the reason and resulting impact
3. Resulting design basis for the revised alternatives and corresponding construction cost estimates
4. Non-economic factors influencing the decision

The description, design criteria, design basis and estimated costs for Alternatives H-2 and AS-1 developed in the Act 537 Special Study are presented in the table below.

Table 1. Alternatives H-2 and AS-1 as provided in the Act 537 Special Study

	Alternative H-2	Alternative AS-1
Biological System Description	Use of three existing TFs in parallel followed by pumping to a new activated sludge system. The existing TFs would be rehabilitated with new media and repairs provided to the rotary distributors. The activated sludge system would consist of three new reactors and new aeration system followed by three 160' diameter clarifiers.	Abandonment of the TFs and treatment in a new activated sludge system. The activated sludge system would consist of four new reactors and new aeration system followed by three 160' diameter clarifiers.

	Alternative H-2	Alternative AS-1
Future (BNR) Biological System Description	Additional reactor volume, conversion of the reactors to the 5-Stage Bardenpho process and bypassing a portion of the flow around the TFs; chemical addition	Additional reactor volume, conversion of the reactors to the 5-Stage Bardenpho process; chemical addition
Design flows	20.5 mgd average; 70 mgd peak	20.5 mgd average; 70 mgd peak
TF recycle and forward flow pumping rates	200% recycle flow (up to average influent flow = 41 mgd); 100 % forward flow = 70 mgd	n/a
Estimated TF effluent quality	BOD: 75 mg/l; TKN: 43 mg/l; TSS: 50 mg/l	n/a
Maximum mixed liquor concentration	3,500 mg/l	3,500 mg/l
Minimum monthly average temperature	12^{0} C	12^{0} C
Minimum aerobic SRT	8 days winter; 6 days summer	8 days winter; 6 days summer
Reactor volume	4.5 MG (based on 2.4 MG firm volume required for average conditions)	10 MG (based on 7.5 MG firm volume required for average conditions)
Resulting mixed liquor mass	131,355 lbs (4.5 MG at 3,500 mg/l)	291,900 lbs (10 MG at 3,500 mg/l)
Reactor configuration	3 basins, each 1.5 MG	4 basins, each 2.5 MG
Future reactor sizing	8 basins total, each 1.5 MG (12 MG total)	6 basins total, each 2.5 MG (15 MG total; firm volume of 12.5 MG required)
Clarifier sizing	3 clarifiers, 15' SWD, 160' diameter	3 clarifiers, 15' SWD, 160' diameter
Estimated Capital Costs for Initial Conditions (Entire liquid treatment process, including the above processes)	$43.173 M	$50.708 M
Present worth of major O&M (Entire liquid treatment process, including the above processes)	$14.524 M	$21.335 M
Total present worth (Entire liquid treatment process, including the above processes)	$57.697 M	$72.043 M

Based on the lowest present worth estimated costs, Alternative H-2 was selected. It is noted that the Act 537 Special Study also included evaluations of two additional alternatives FF-1 and H-1, which were not reconsidered during the process re-evaluation due to the findings of the Act 537 Special Study, as discussed in Section 7.

The design modifications, reason and resulting impact on the design basis are described in the table below. Further detail of each design modification is provided below the table.

Table 2. Summary of Modifications to Design Criteria for Alternative H-2

No.	Modification to Design Criteria	Reason/Source	Impact on Design Basis of Alternative H-2
1	Minimum design SRT of 12 days due to slower than typical nitrification rate	Wastewater characterization / nitrification kinetics study using the Low F:M SBR protocol (kinetics study)	Increased reactor volume required/ increased design MLSS to accommodate the increased mixed liquor requirement
2	Design peak flow increase to 83.4 mgd	Re-evaluation of all plant flow sources	Increase the number of clarifiers from 3 to 4
3	Decrease minimum design temperature to 10.5 degrees (based on 6-day average of effluent temperatures)	Re-evaluation of plant data - effluent temperatures captures the cooling effect of the TFs	Increases the volume of the required reactors/ MLSS due to impacts on nitrification rates
4	Increased TF effluent TSS projection	Information provided by Brentwood Industries (manufacturer of TF media) and EnviroSim modeling of the TFs demonstrated higher levels of TSS leaving the TFs than projected in the Act 537 Special Study	Increased the required reactor volume/ MLSS to accommodate greater total mixed liquor requirements
5	Modify the reactor design to a step-feed process	Based on input from the City's PM/CM team	Enabled increased MLSS mass for a given reactor volume
6	Need to add a snail removal process downstream of the TFs	Based on site visits and investigations at other facilities using the hybrid process	Additional costs for a new snail removal system
7	Capacity of the existing rotary distributors/ TF piping and effluent channels	The existing rotary distributors require replacement due to limited hydraulic capacity	Additional costs for replacement (rather than rehabilitated rotary distributors)

The reasoning/source of each modification is discussed further below:

1. **Increased SRT - Wastewater Characterization/Nitrification Kinetics Study**

The minimum design SRT for the activated sludge system increased based on findings of the Nitrification Study performed during the summer 2013 by EnviroSim. This section summarizes the findings of

EnviroSim's draft report "City of Reading Improvements to the Fritz Island Wastewater Treatment Plant - Wastewater Characterization / Nitrification Study" dated August 30, 2013.

The primary objectives of this work were to evaluate the nitrification kinetic parameters (*i.e.* primarily the nitrifier maximum specific growth rates, μ_{AOB} and μ_{NOB}) for a nitrifying activated sludge system treating the Fritz Island WWTP raw wastewater, and to determine the wastewater characteristics of the raw wastewater. This information was used in sizing the activated sludge process (and related processes) for the Fritz Island WWTP expansion.

The approach used to estimate the wastewater characteristics and nitrification kinetics of the Fritz Island wastewater generally followed the low F:M procedure presented in the Water Environment Research Foundation wastewater characterization report (WERF, 2003). The low F:M protocol involves operating a bench-scale sequencing batch reactor (SBR) for several weeks to attain a *quasi* steady-state, and then conducting intensive monitoring over a period of approximately two weeks.

Important conclusions/observations from the study are listed below:

- The raw influent strength is high. The average COD over the 47-day system start-up period was 822 mg/L; the average COD over the 11-day intensive monitoring period was 732 mg/L.
- The raw influent appears to be more soluble in nature than a typical municipal wastewater.
- The nutrient content of the wastewater is low relative to the organic strength.
- The unbiodegradable particulate fraction of the influent total COD (f_{UP}) is 0.10 mg COD / mg COD. This value is lower than the typical value of 0.13 mg COD / mg COD for a raw municipal wastewater and is in fact close to the typical value of 0.08 mg COD / mg COD for a primary settled wastewater.
- Sludge production for the bench-scale activated sludge system operated on Fritz Island raw wastewater was observed to be typical at the estimated SRT of 9.74 d and f_{UP} of 0.10 mg COD / mg COD.
- The nitrification behavior in the system could be simulated accurately with a μ_{AOB} value of 0.62 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d^{-1}], and a μ_{NOB} value of 0.70 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d-1]. This μ_{AOB} value is lower than the BioWin default value of 0.9 d^{-1} which is based on nitrification rate tests conducted at numerous North American plants. The observed μ_{AOB} value of 0.62 d^{-1} suggests that the ammonia oxidizing bacteria (AOB) were inhibited in the current study.

The impact of these findings, specifically the slow nitrification rate, is that a greater mass of mixed liquor in the suspended growth reactors would be required to accomplish the treatment objectives in comparison to the mass that was contemplated in the Act 537 Special Study for both the initial and the future conditions.

Subsequent to the preparation of the Wastewater Characterization/Nitrification Kinetics Study, EnviroSim developed a BioWin model based on the wastewater characterization, observed nitrification rate, and influent data evaluated for the Liquid TM. The BioWin model included the TFs, proposed clarifiers and solids treatment system. The minimum design SRT for the H-2R Alternative was determined to be 12 days through EnviroSim's work.

Preliminary models prepared by EnviroSim for the H-2 configuration resulted in the required mixed liquor mass shown in the table below.

Table 3. Preliminary MLSS mass requirements for H-2 based on observed nitrification rate

Design minimum temp (^oC)	Aerated reactor volume required (MG)	MLSS Required (mg/l)	Corresponding MLSS mass (lbs)
12	7.5	4,067	254,390
10.5	7.5	4,149	259,520

The MLSS mass provided by the 4.5 MG tankage operating at 3,500 mg/l, as proposed by the Act 537 Special Study results in a MLSS mass of 131,355 lbs, which is considerably less than the mass requirement determined through preliminary modeling.

2. Design peak flow increase and final clarifier sizing

The Act 537 Special Study indicated three (3) new final clarifiers will be constructed, each 160 ft. diameter with a 15 ft sidewater depth. The Act 537 Special Study indicated sludge underflow will be pumped with new RAS pumps housed in a new pumping station with the capacity being 150% of the average flow. The Act 537 Special Study anticipated the reactor mixed liquor concentration to be 3,500 mg/L.

While the Act 537 Special Study was predicated on a peak hourly flow rate of 70 mgd to the primary clarifiers, confirmation of the peak hourly flow rate was to be determined during preliminary design. The City's basic criteria for the upgraded facility is that it not be a hydraulic bottleneck in the City's wastewater system; i.e., none of the wastewater that is conveyed to the upgraded Fritz Island WWTP shall overflow any of the treatment units. To identify the peak hourly flow rate, an investigation was performed during the preparation of the Liquid TM, in concert with the City staff, of the hydraulic capacity of the facilities in the collection and conveyance system that contribute flow to the wastewater treatment facility.

The design peak hourly flow to the WWTP was established to be 84.3 mgd as shown in the table on the next page, which is significantly higher than the 70 mgd identified in the Act 537 Special Study.

Table 4. Derivation of Peak Hourly Flows as presented in the Liquid TM

Facility	Peak Hourly Flow (mgd)
6th and Canal Sts PS	60.00
18th Ward PS	18.73
Cumru Sewer System	3.04
Flying Hills PS	2.50
Total	**84.27**

As noted above, an increase to the design total mixed liquor mass was required due to the lower design temperature and slower than anticipated nitrification rate. The increase in mixed liquor mass will be accommodated through larger reactors and by increasing the design mixed liquor concentration. The design mixed liquor for the revised alternative H-2R (detailed below) is approximately 4,300 mg/l. Based on both the increased design mixed liquor concentration and peak flow, and that one final clarifier would be out of service at times, the loadings were re-evaluated to determine if three 160 ft. diameter clarifiers would be sufficient. Loading scenarios were tabulated as shown below.

Table 5. Final Clarifier Loading Scenarios

	3 Clarifiers	**1 out of service**	
Average hydraulic loading rate	358	537	gpd/sf
Peak hydraulic loading rate	1,471	2,207	gpd/sf
Average solids flux	26	39	lbs/d/sf
Peak solids flux (peak flow and 100% RAS)	66	99	lbs/d/sf
	4 Clarifiers	**1 out of service**	
Average hydraulic loading rate	268	358	gpd/sf
Peak hydraulic loading rate	1,103	1,471	gpd/sf
Average solids flux	21	26	lbs/d/sf
Peak solids flux (peak flow and 100% RAS)	49	66	lbs/d/sf

The loadings tabulated above were compared to the loading criteria and guidelines shown in the table on the following page. The loading criteria that are the most appropriate for the trickling filter / activated sludge nitrification system that will be used is a hybrid of the "separate stage nitrification" and "single stage nitrification" categories.

Table 6. Final Clarifier Loading Criteria and Guidelines

DEP Domestic Wastewater Facilities Manual					
	Average Hydraulic Loading Rate (gpd/sf)	Peak Hydraulic Loading Rate (gpd/sf)	Average Solids Flux (lbs/d/sf)	Peak Solids Flux (lbs/d/sf)	Maximum Monthly Average Weir Loading Rate (gpd/lf)
Conventional Activated Sludge	800	1,200	40	50	15,000
Separate Stage Nitrification	500	800	30	50	
M&E Wastewater Engineering 4th Edition					
	Average Hydraulic Loading Rate (gpd/sf)	Peak Hydraulic Loading Rate (gpd/sf)	Average Solids Flux (lbs/d/sf)	Peak Solids Flux (lbs/d/sf)	Peak Weir Loading Rate (gpd/lf) (1)
Conventional Activated Sludge	400-700	1,000-1,600	19-29	38.4	20,000

10 States Standards Guidelines			
	Peak Hydraulic Loading Rate (gpd/sf)	Peak Solids Loading Rate (lbs/d/sf)	Peak Weir Loading Rate (gpd) (2)
Conventional	1,200	50	30,000
Single Stage Nitrification	1,000	35	
Meeting < 20 mg/L TSS	1,000	--	
Meeting < 1 mg/L TP	900	35	

(1) Weir located in upturn zone of density current
(2) Average plant capacity > 1 mgd

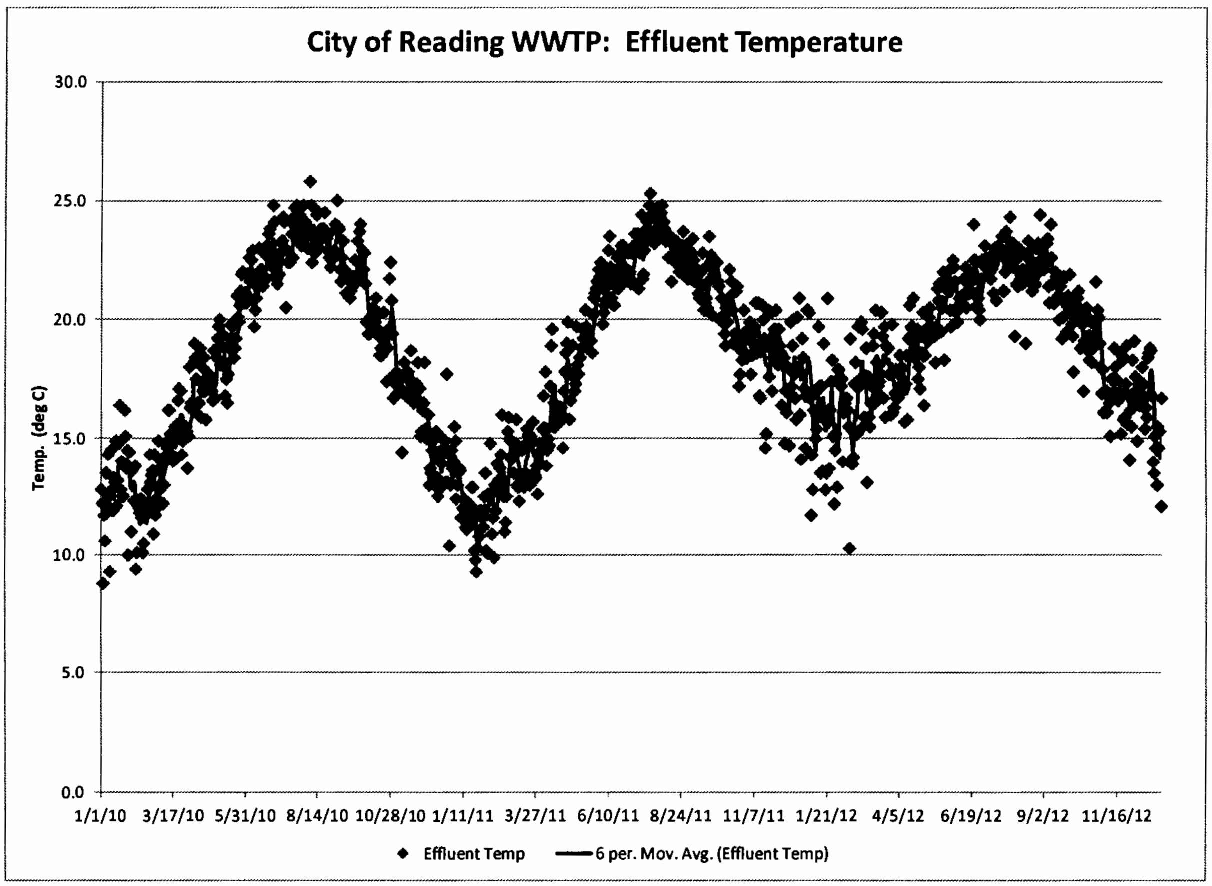
If three clarifiers were to be used, the loading rates with one clarifier out of service are higher than typical design values and far exceed DEP guidelines. In order to minimize the impact of taking a clarifier out of service, it was recommended in the Liquid TM to construct four clarifiers instead of three.

3. Revision to a minimum design temperature of 10.5°C

As indicated above, a review of the plant data indicated it was appropriate to use a minimum wastewater design temperature of 10.5°C. The selection of 10.5^{0} C was based on a 6-day rolling average of effluent temperatures. A six-day average was selected since it is thought that the sensitive nitrifiers will not be significantly impacted from a cold period with a duration of half the design SRT. Effluent temperatures were evaluated (rather than influent) to capture the cooling effect of the TFs. Due to the lower design temperature compared to the Act 537 Special Study design temperature of 12^{0} C, an increase in the minimum design SRT (and subsequently mixed liquor mass) was required. Of note, the minimum day temperature was observed to be 9^{0} C based on the data shown below.

The effluent temperatures and 6-day rolling average are shown in the figure below.

Figure 2. Effluent temperature data and 6-day rolling average



4. Analysis of upgraded trickling filter performance

As the preliminary design progressed, RK&K worked with Brentwood Industries (Brentwood) (manufacturer of TF media) and EnviroSim to further develop TF effluent characteristics for use in sizing the new downstream, activated sludge reactors. With the proposed system for Alternative H-2, the TFs primary function was to remove a significant portion of the influent BOD to reduce aeration requirements in the activated sludge reactors. The TFs were not being used for nitrogen removal. Through the BOD conversion, the TFs generate biomass, which is periodically sloughed as TSS. The Alternative H-2 did not propose to use intermediate clarifiers following the TFs, and therefore, the TF effluent TSS needs to be considered as a component of the MLSS in the activated sludge reactors. Accurate predictions of the anticipated upgraded TF (with new plastic media) effluent BOD and TSS are critical for sizing of the downstream activated sludge system.

At RK&K's request, Brentwood provided projections of the TF performance based on median loadings and maximum month loadings provided by RK&K. The projected characteristics of the TF effluent as provided by Brentwood are summarized in the following table.

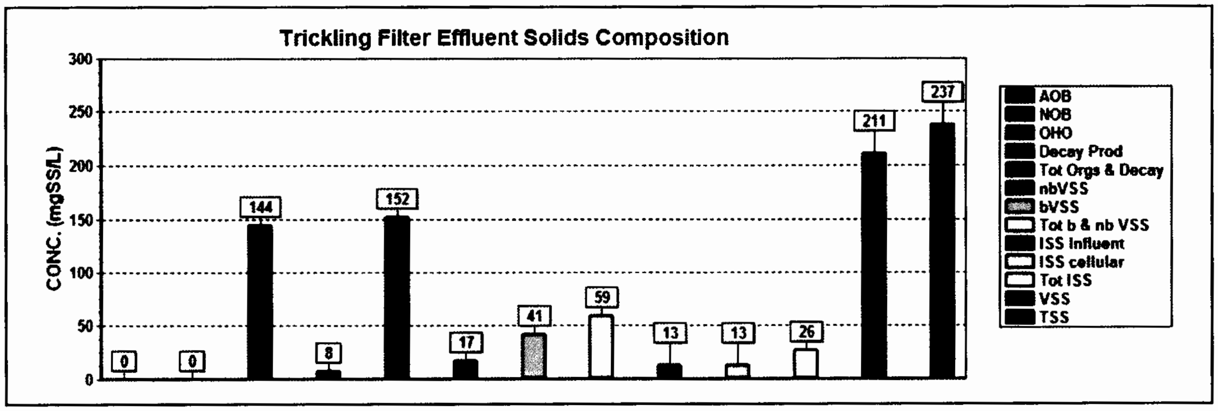
Table 7 – Brentwood's projections of trickling filter effluent quality

	Median Loading Condition	Max. Month Loading Condition
TF Effluent Total BOD (mg/l)	184	267
TF Effluent Soluble BOD (mg/l)	41	62
TF Effluent NH3 (mg/l)	34.5	39.6
TF Effluent TSS (mg/l)	222	306

Brentwood's correspondence to RK&K with these projections is included in the Appendix.

TF performance was also determined by preliminary BioWin modeling. The BioWin model included a TF element in addition to the activated sludge system. The findings of the preliminary BioWin modeling were provided in an October 24, 2013 technical memorandum that is included in the Appendix. The preliminary BioWin model was based on a SRT of 12 days (due to the slow nitrifier growth rate found during the Wastewater Characterization/Nitrification Kinetics study) and on a minimum design temperature of 12°C. Subsequent modeling was performed at the revised lower design temperature of 10.5°C. The projected TF effluent solids composition from the preliminary modeling is shown in the graph on the next page.

Figure 3. Trickling filter effluent solids composition prediction from EnviroSim modeling



The projected characteristics of the TF effluent based on the EnviroSim modeling are shown in the table below.

Table 8. Projection of trickling filter effluent quality from preliminary EnviroSim modeling

	Median Loading Condition Range
TF Effluent BOD (mg/l)	239-253
TF Effluent Soluble BOD (mg/l)	90-121
TF Effluent TSS (mg/l)	214-239

The projected performance based on input from Brentwood and preliminary BioWin modeling were in very good agreement and differed markedly from the estimated TF effluent quality of 50 mg/l TSS presented in Table 6-4 the Act 537 Special Study.[1] The impact of using the updated TF effluent TSS loading is that a greater mass of mixed liquor in the suspended growth reactors would be required to accomplish the treatment objectives in comparison to the mass that was contemplated in the Act 537 Special Study for both the initial and the future conditions. The preliminary modeling work completed by EnviroSim indicated a MLSS of 6,137 mg/l would be required for an activated sludge reactor system of 4.5 MG (equates to a MLSS mass of 230,322 lbs). Operating at such a high MLSS is outside of the normal range of conventional activated sludge / secondary clarifier technology and therefore, a reactor volume greater than 4.5 MG is required to maintain the required MLSS mass. BioWin modeling indicated that 7.5 MG of reactor volume was required to operate at an acceptable MLSS concentration of 4,149 mg/l.

5. Conceptualization to use a step feed reactor configuration (by PM/CM Team)

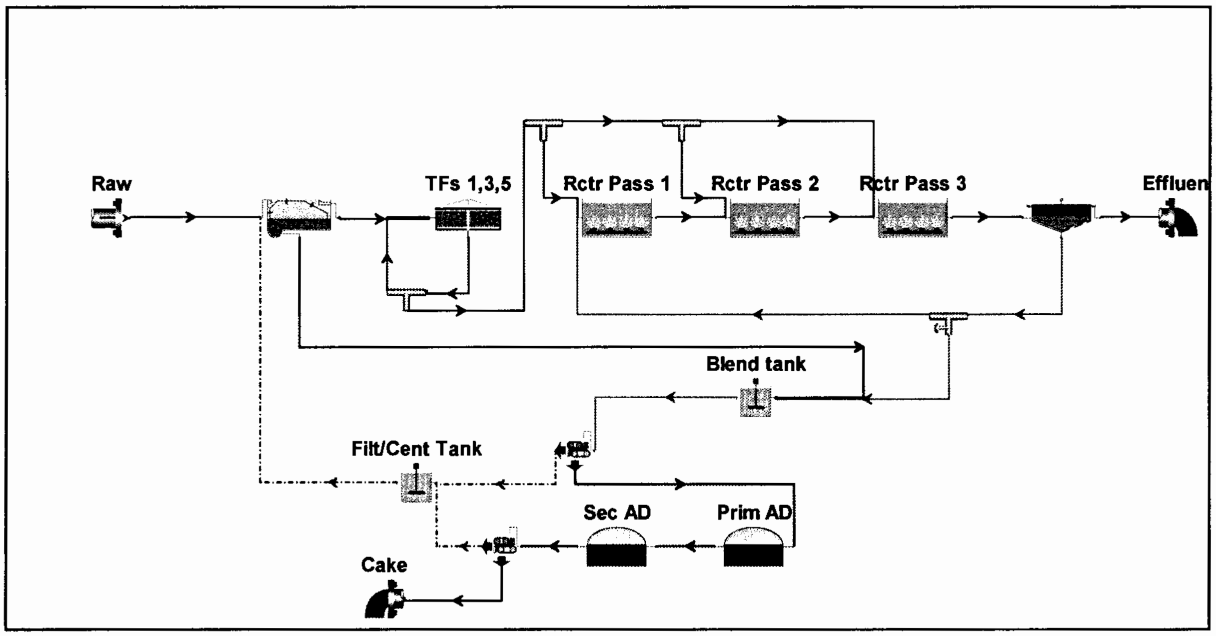
In response to the finding that a greater mass of mixed liquor would be required, the PM/CM Team re-evaluated process alternatives to develop a cost effective approach to accommodating the additional mixed liquor. One of their suggestions in its November 15, 2013 memorandum (included in the

[1] Table 6-4 was also applicable to Alternative H-2.

Appendix) was to use a step feed reactor configuration for Alternative H-2 instead of a plug flow configuration. A step feed configuration would enable a greater mass of mixed liquor to be carried in the reactors without impacting the clarifier size required. The City and RK&K reviewed the PM/CM's suggestion to use a step feed system.

The proposed step feed system would consist of dividing the influent flow to the reactors at three locations, with the tank portioned into thirds. The RAS would continue to be returned to the influent end of the reactor. A process schematic of the proposed system in BioWin modeling is shown below. The step-feed process allows the MLSS to operate at higher concentrations at the upstream end of the reactors. The process provides flexibility to allow influent feed to be bypassed to the downstream portion of the tank during high flow events to preserve the MLSS. The step-feed process was termed Alternative H-2R.

Figure 4. Step-Feed Process Schematic from BioWin Modeling



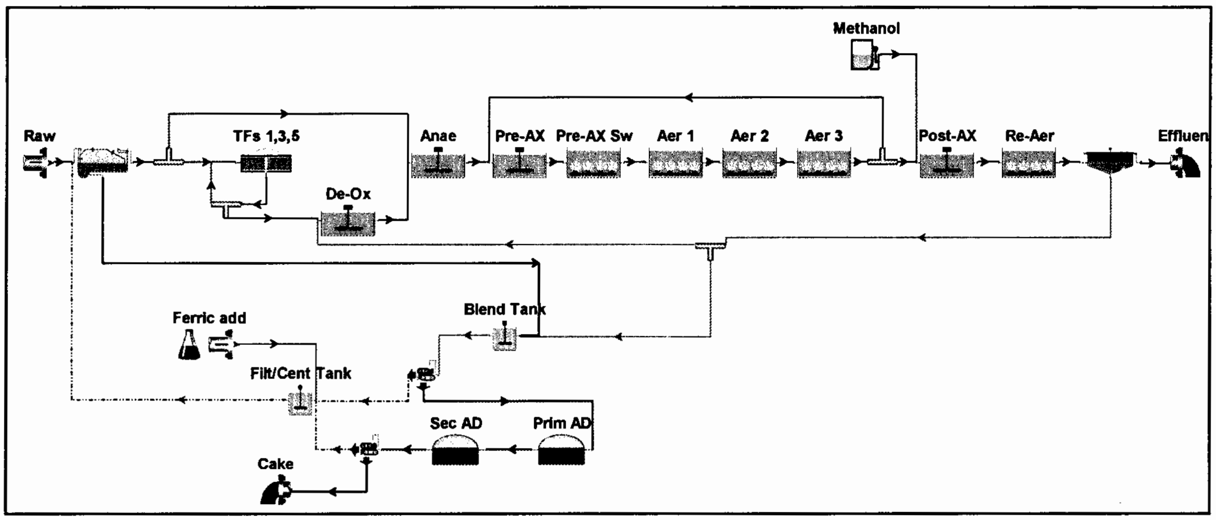
By utilizing the step-feed process, the required activated sludge reactor volume is reduced from 7.5 MG to 6.0 MG. RK&K performed independent calculations using BioWin modeling and concurred that an acceptable design for initial conditions could be achieved using 6.0 MG reactor volume in a step feed configuration with an average MLSS concentration of 4,311 mg/L at 10.5°C for Alternative H-2R.

The step feed system will be configured to allow flow to be split evenly by thirds, or in half if the most upstream feed point is not utilized. Weirs will be used to the split the flow. There will be no means of adjusting or throttling the flow to each zone.

For future BNR conditions, the PM/CM Team recommended bypassing one-half of the primary effluent flow around the TFs and feeding it to the anaerobic zone of a Five-Stage Bardenpho reactor while feeding the TF effluent to the oxic zone. The purpose of partially bypassing the TFs was to avoid feeding TF effluent with a high dissolved oxygen concentration of approximately 4 mg/L to the anaerobic zone. The City indicated it preferred not to use this step feed approach for the future BNR reactors and that plug flow reactors should be used for BNR. Therefore, the step feed process would be abandoned at the future BNR upgrade.

RK&K/Envirosim performed independent calculations using BioWin modeling for plug flow Five-Stage Bardenpho reactors following TFs and confirmed the approach to partially bypass the TFs was required. To minimize the flow bypassed around the TFs, RK&K suggested using a de-oxygenation zone between the TFs and the reactors. The de-oxygenation zone would be 0.45 mg. For this process configuration, RK&K found a plug flow Five-Stage Bardenpho reactor volume of 12 mg operating at 4,651 mg/l MLSS would be required for future BNR conditions. A process schematic of the future BNR process system from the BioWin modeling work is shown below.

Figure 5. Future BNR Process Schematic from BioWin Modeling (for Alternative H-2R)



6. Need for Snail Removal

TF snails are currently present throughout the Fritz Island WWTP. RK&K has observed them in the clarifiers downstream of the TFs, in the Tertiary Aeration Basins and in the sludge cake in the roll-off containers. The City reported that snails are also present in digesters when they are taken out of service for cleaning. The nearby Wyomissing WWTP, which utilizes the hybrid TF/AS process, experiences snail accumulation in the aeration tanks. The snails accumulate to such an extent that the aeration tanks need to be drained annually for removing the snails. Problems with TF snails have been reported at many wastewater treatment plants in technical papers[2]. RK&K visited the Wyomissing WWTP and contacted a facility in Echonate, Alabama that recently switched to new plastic TF media. Both facility contacts responded that the snail problem increased significantly after new TF media was provided. At the 3 mgd Wyomissing WWTP, the plant superintendent estimated that 45-60 tons per year of snails are generated.

The City and RK&K believe there is a high probability that snails will be present in the hybrid system. There is concern that if no measures are taken to control their growth, or if no measures are taken to prevent them from entering the new activated sludge system, there will be operation and maintenance problems from snails clogging pipes, causing wear on pumps, covering aeration diffusers and filling space in tanks, thereby reducing available volume for treatment.

The City indicated that the design of the TF upgrades should allow the filters to be flooded and to elevate the pH to control snail growth. It is also believed that having the operational flexibility to control the rotary distributor speed will assist in controlling snail growth. Accordingly, the following measures were incorporated in the design:

- Structural repairs would be made to the TF tanks to eliminate leaks to enable the TFs to be flooded
- Speed control would be provided for the new rotary distributors
- Provisions would be made for feeding caustic soda to the TF distribution structure in the future

In addition, a snail removal system was proposed, with its optimal location in the TF effluent piping conveyance system. Using this location will minimize the quantity of snails that enter the Intermediate/Recycle PS which would be recirculated to the TFs and to the activated sludge system. However, the snail removal system would need to be constructed deep below grade and consequently it would be relatively costly. The second most favorable location is on the force main from the Intermediate / Recycle PS to the Reactor Distribution Box. This would minimize transport of the snails to the new activated sludge system. Compared to the optimal location, excavation quantities would be greatly reduced with a large portion of the units being above grade. The system should be sized to handle the peak hourly flow rate. The snails are observed to both sink and float. Several snail removal options were evaluated, including:

- Use of a custom-designed tank that creates a "wide-spot" in the TF effluent conveyance system in which the snails settle due to the low velocity. Submersible pumps would be used to remove the snails. Coarse bubble diffusers would be used to fluidize the snails prior to pumping. The snails would be pumped to a concentrator system and ultimately be deposited in containers for hauling to a landfill. The design would be based on a similar system installed at the Ryder Street WWTP in Vallejo, California. A concern with this type of system is configuring it so it does not capture a significant amount of solids concurrently with the snails. It is recognized that, besides the Vallejo

[2] For example: Trickling Filter and Trickling Filter-Suspended Growth Process Design and Operation: A State-of-the Art Review by Glen T. Daigger and Joshua P. Boltz, Water Environment research, Volume 83, Number 5.

system, there may be a limited number of facilities in operation from which to draw upon their experience to design the system for the Fritz Island WWTP. A technical paper discussing the Vallejo, California system is included in the Appendix.

- The use of Hydro International's Grit King vortex-type grit removal system was considered. It is envisioned two Grit King units would be provided and snails would be pumped to a unit functioning as a concentrator, then to a classifier/clarifier unit and then deposited in a container for hauling and disposal off-site.

The Liquid TM recommended the use of Hydro International's Grit King vortex-type unit. The snail removal system will require significant excavation. A building housing the snail dewatering and dumpster loading would be required.

7. **Hydraulic Capacity of the Existing Rotary Distributors/TF Piping and Channels**

Evaluation of the TFs during the preparation of the Liquid TM led to the conclusion that the hydraulic capacity of the TFs needs to be increased. In each of TF Nos. 1, 3 and 5 (which were the three TFs identified for rehabilitation), the hydraulic capacity of the following components needs to be increased:

- Influent pipe
- Rotary distributor
- Effluent channel within the TF
- Effluent box
- Effluent sluice gate
- TF Effluent yard piping

The maximum flow that has historically been conveyed to each existing primary TF is approximately 21 mgd. This is based on the consideration that the primary clarifiers are reported to have overflowed at influent flows of 55-60 mgd and TF recycle flows have been limited to 8 mgd, resulting in a maximum total flow of approximately 63 mgd to all three TFs. The design peak flow to each TF will be approximately 30 mgd (forward flow plus in-plant recycles), when all units are in service during peak hourly flows. When operating under more normal influent flow conditions at the recommended wetting rate, the flow to each of the three TFs will be approximately 20.5 mgd. Correspondence with Westech, Ovivo and Walker Process indicate a rotary distributor larger than the existing would be required to handle 30 mgd, with center column sizes of 48-inches required necessitating the replacement of the existing 36-inch center columns.

Based on hydraulic capacity considerations, the Liquid TM recommended to replace the entire rotary distributor in each TF rather than only replace the distributor arms, turnbuckles and cables and repair the center column that was originally contemplated in the Act 537 Special Study.

SECTION 4. REVISED ALTERNATIVE H-2R

The modifications to the design criteria for Alternative H-2 resulted in a revised design basis which was identified as Alternative H-2R as described above. A description of the revised alternative and associated design criteria is provided below.

Table 9. Revised Alternative H-2R

	Alternative H-2R
Biological System Description	Use of three existing Tfs in parallel followed by pumping to a new activated sludge system. The existing TFs would be rehabilitated with new media and repairs provided to the rotary distributors. The activated sludge system would consist of four new step feed reactors and new aeration system followed by four 160' diameter clarifiers.
Future (BNR) Biological System Description	Additional reactor volume, conversion of the reactors to the 5-Stage Bardenpho process in a plug flow configuration and bypassing 50% of the flow around the TFs; chemical addition
Design flows	20.5 mgd average; 84.3 mgd peak
TF recycle and forward flow pumping rates	54 mgd recycle flow; 89 mgd forward flow
Estimated TF effluent quality range	TSS: 222-237 mg/l; NH3: 32.6-34.5 mg/l; BOD: 165-184 mg/l
Snail removal system	Either vortex or custom tank/chamber design
Mixed liquor concentration at clarifiers	4,311 mg/l
Average mixed liquor concentration in reactors	5,306 mg/l
Minimum monthly average temperature	10.5^{o} C
Minimum aerobic SRT	12 days
Reactor volume	6.0 MG total
Reactor configuration	4 basins, each 1.5 MG; step feed in thirds
Future reactor sizing	12 MG total
Future configuration	8 basins, each 1.5 MG, plug flow; 50% flow bypassed around TFs
Future MLSS concentration	4,651 mg/l
Clarifier sizing	4 clarifiers, 15' SWD, 160' diameter

A site plan for the proposed Alternative H-2R is included at the end of this Section.

Partial cost estimates were developed for the revised Alternative H-2R that included only the biological system: TFs, distribution structures, snail removal (for both the chamber and vortex system options), Intermediate/Recycle PS, and activated sludge reactors. Partial operational costs were developed based on major electrical uses only for the forward and recycle pumping, snail removal system, and aeration and were based on an electric rate of $0.079/kWh (derived from billing information provided by the

City). Details of the partial construction and operational cost estimates are included in the Appendix and the summary list below includes additional electrical/I&C costs. The partial cost estimate is shown in the table below.

Table 10. Estimated Partial Construction Costs for Revised Alternative H-2R

Unit Process	Estimated Partial Construction Costs
TF Distribution Structure	\$1.874 M
TF Rehabilitation (including media and rotary distributor replacement, piping/hydraulic expansion, structural repairs)	\$13.675 M
Snail Removal System	\$6.335 M (vortex system); \$2.5 M (chamber system)
Intermediate/Recycle Pumping Station	\$10.388 M
Activated Sludge Reactors (6.0 MG in step-feed configuration)	\$15.755 M
Partial Construction Cost	\$48.027 M (vortex system); \$44.192 M (chamber system)

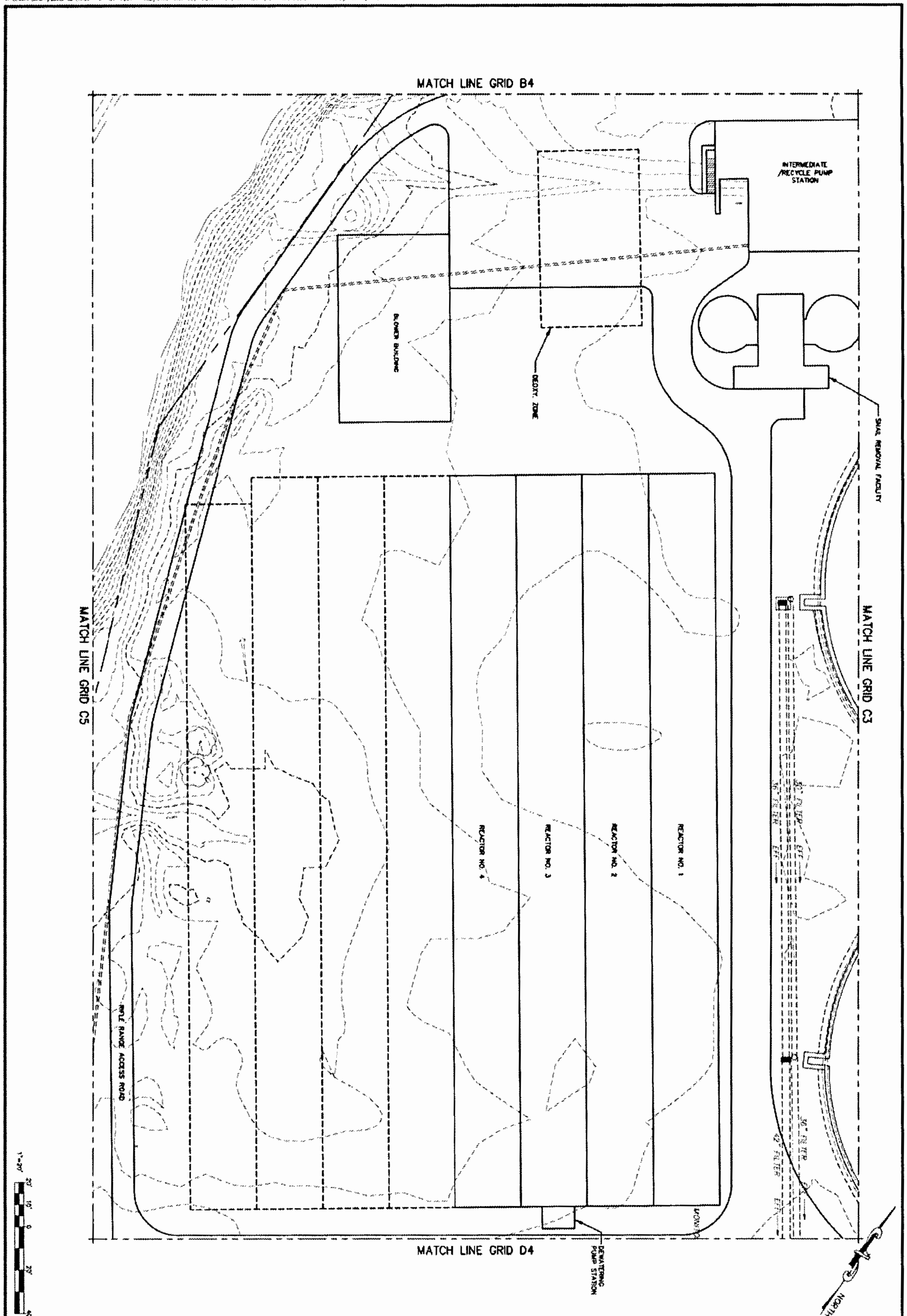
The estimated 20-year present worth of the partial operational costs are shown in the table below.

Table 11. Estimated Present Worth of Partial Operational Costs for Revised Alternative H-2R

Unit Process	Estimated Present Worth of Partial Operation Costs
Aeration electrical cost	\$7.707 M
Forward flow pumping electrical cost	\$0.882 M
TF recycle flow pumping electrical cost	\$1.841 M
Snail removal system operational electrical cost (no disposal costs included)	\$0.850 M (vortex system); \$0.143 M (chamber system)
Partial Present Worth Cost	\$11.281 M (vortex system); \$10.574 M (chamber system)

The total partial present worth (construction and operational) for Alternative H-2R is \$59.308 M (vortex snail system) or \$54.766 M (chamber snail system).

The above costs do not include the remaining liquid treatment processes included in the cost estimate provided in the Act 537 Special Study (primary treatment, blower building, final clarifiers, RAS/WAS Pump Station, disinfection, outfall, utility water, etc.). In consideration of the costs for the unit processes associated with the TFs being considerably higher than the costs associated with the suspended growth reactors, and the estimated costs for only the biological treatment system portion of the liquid train being \$44-48 M, compared to the entire liquid train process construction estimate of \$42.66 M in the Act 537 Special Study, RK&K re-evaluated Alternative AS-1 to determine if the modifications to the design criteria would influence the relative cost of the revised alternatives.



CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP
BERKS COUNTY PENNSYLVANIA

SITE PLAN H-2R

ENGINEER	DESIGNED BY
DPB	RJA
DRAWN BY	DATE
SEB	11/2013
PROJECT NUMBER	
213-054	

DRAWING NUMBER
FIGURE 6
SHEET NO OF X

NO	DESCRIPTION	BY	DATE

REVISIONS

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RUMMEL, KLEPPER & KAHL, LLP
3501 CONCORD ROAD
SUITE 100
YORK, PENNSYLVANIA 17402

SECTION 5. REVISED ALTERNATIVE AS-1R

In order to re-evaluate the costs for an all-activated sludge alternative (AS-1 in the Act 537 Special Study), the design refinements and updated design criteria developed during the preliminary design were applied and used to develop a revised alternative, termed AS-1R. A portion of the modifications to the design criteria for Alternative H-2 also affected the proposed Alternative AS-1 contemplated in the Act 537 Special Study. Those modifications are shown in the table below.

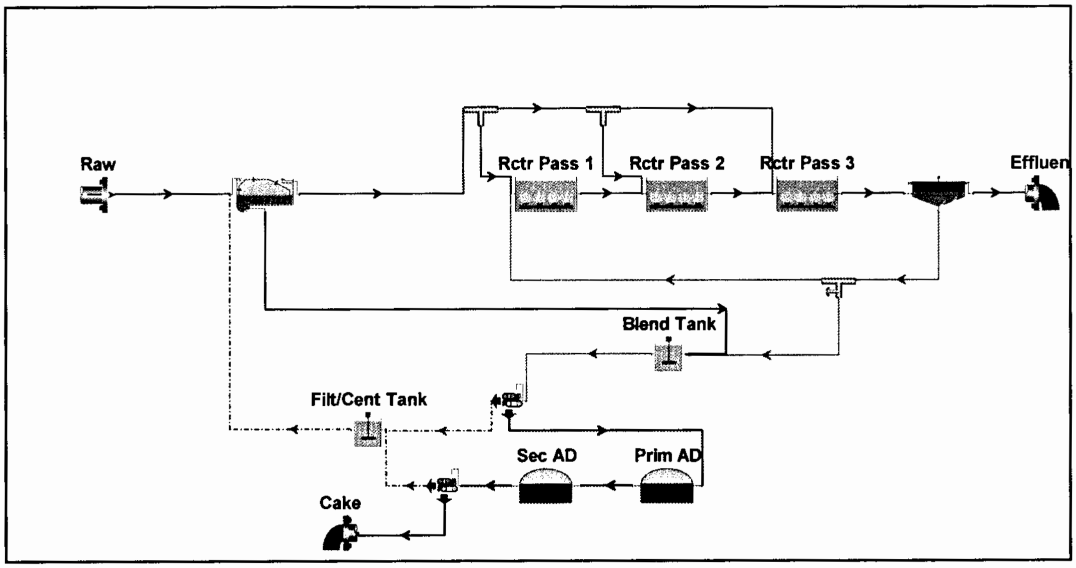
Table 12. Summary of Modifications to Design Criteria Affecting Alternative AS-1

No.	Modification to Design Criteria	Reason/Source	Impact on Design Basis of Alternative AS-1
1	Minimum design SRT of 15 days due to slower than typical nitrification rate	Wastewater characterization / nitrification kinetics study using the Low F/M SBR protocol (kinetics study)	Increased reactor volume required/ increased design MLSS to accommodate the increased mixed liquor requirement
2	Design peak flow increase to 84.3 mgd	Re-evaluation of all plant flow sources	Increase the number of clarifiers from 3 to 4
3	Modify the reactor design to a step-feed process	Based on input from the City's PM/CM team	Enabled increased MLSS mass for a given reactor volume

As discussed above, the findings of the Wastewater Characterization/Nitrification Kinetics Study indicated that an increased SRT was required due to the lower than typical nitrification rate. Based on preliminary BioWin modeling performed by EnviroSim, a minimum design SRT of 15 days is required for the AS-1R alternative. Similar to H-2R, the use of the step-feed process was proposed to reduce the quantity of additional reactor volume required to accommodate the additional MLSS. The proposed AS-1R, implements step feed similar to H-2R, with three influent feed points at the upstream, 1/3rd and 2/3rd portion of the tank. Since TFs are not used, there is no need for snail removal or the Intermediate/Recycle PS. Primary effluent will be sent directly to the activated sludge reactors via gravity.

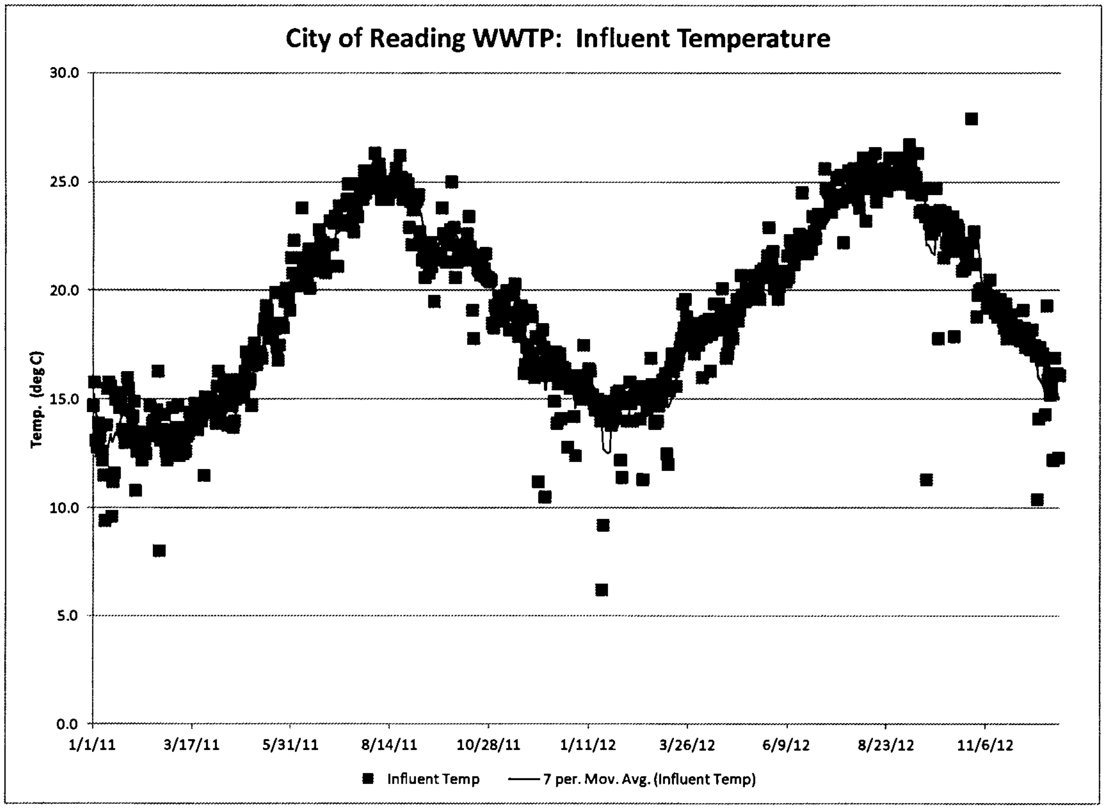
A process schematic of the proposed AS-1R alternative from the BioWin modeling is shown on the next page.

Figure 7. AS-1R Schematic from BioWin Modeling



In order to determine the minimum design temperature, influent data were analyzed based on a 7-day rolling average. The selection of 7-days was based on being half the minimum design SRT of 15 days. The influent data were used rather than effluent data since the TF would not provide a cooling effect for an all activated sludge alternative. The minimum 7-day rolling average temperature was 12.2 ^{0}C. Temperature data is shown in the figure on the next page.

Figure 8. Influent Temperature and Rolling 7-Day Average



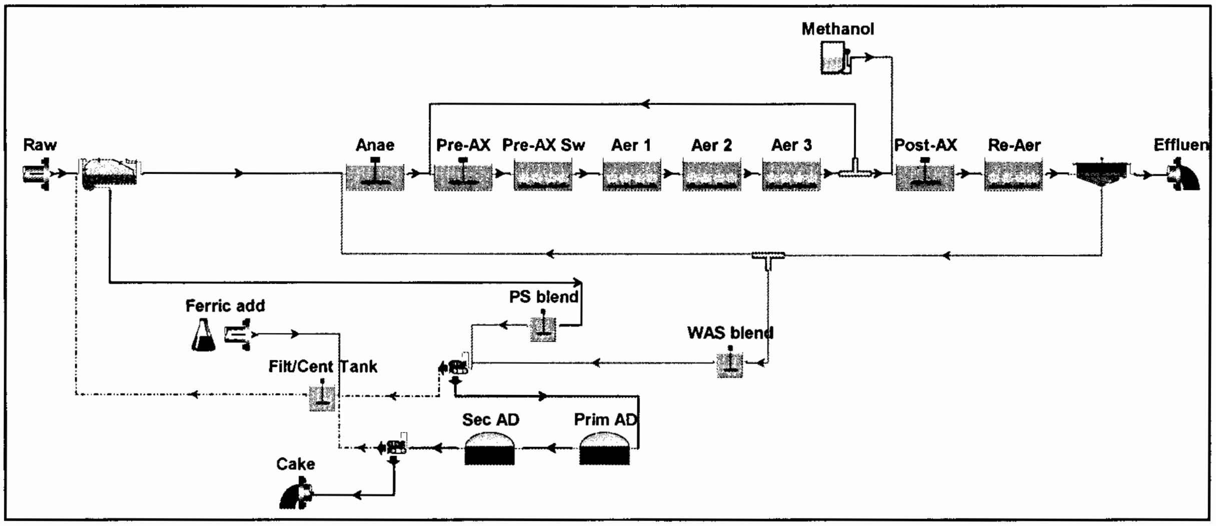
Preliminary models prepared by EnviroSim for the AS-1R configuration resulted in the required mixed liquor mass shown in the table below. Details of the modeling output are included in the Appendix.

Table 13. Preliminary MLSS Mass Requirements for AS-1R in the Step-Feed Configuration

Design minimum temp (^{0}C)	Aerated reactor volume required (MG)	Average MLSS Required (mg/l)	MLSS in last step-feed zone (mg/l)	Corresponding MLSS mass (lbs)
12.2	7.5	5,503	4,300	344,234

The future BNR system would be configured as a Five-Stage Bardenpho and the step-feed configuration would be modified to the plug flow configuration. The reactor volume would be increased from 7.5 MG to 15 MG. A process schematic of the proposed future BNR schematic from the BioWin modeling of the future BNR system is shown on the next page. The preliminary BioWin modeling was used to proportion the future 5-Stage zone volumes and to determine that a design MLSS of 4,481 mg/l was required at the minimum design temperature of 12.2^{0}C. Details of the modeling output are included in the Appendix.

Figure 9. Future BNR – Schematic from BioWin Modeling



The design criteria for the revised Alternative AS-1R are provided in the table below. A site layout of the proposed AS-1R is included at the end of this section.

Table 14. Revised Alternative AS-1R

	Alternative AS-1R
Biological System Description	Abandonment of the TFs and treatment in a new activated sludge system. The activated sludge system would consist of four new reactors and new aeration system followed by four 160' diameter clarifiers.
Future (BNR) Biological System Description	Additional reactor volume, conversion of the reactors to the 5-Stage Bardenpho process; chemical addition
Design flows	20.5 mgd average; 84.3 mgd peak
Mixed liquor concentration at clarifiers	4,300 mg/l
Average mixed liquor concentration	5,503 mg/l
Minimum monthly average temperature	12.2^{0} C
Minimum aerobic SRT	15 days
Reactor volume	7.5 MG total
Reactor configuration	4 basins, each 1.875 MG; step feed in thirds
Future reactor sizing	15 MG total
Future reactor configuration	8 basins, each 1.875 MG; plug-flow; 5-Stage Bardenpho
Future design MLSS	4,481 mg/l
Clarifier sizing	4 clarifiers, 15' SWD, 160' diameter

Of note, the total connected load for the major pumping and aeration equipment was calculated for both revised alternatives and found to be similar: 3,725 hp for H-2R and 3,500 hp for AS-1R. Therefore, no further development of the plant electrical service costs were calculated since both systems would require similar size service.

Partial cost estimates were developed for the revised Alternative AS-1R. Partial cost estimates were prepared for the biological system only for comparison with H-2R. The estimated costs of the additional aeration system requirements (due to the higher demand compared with H-2R) and additional influent yard piping were calculated for comparison with H-2R. Comparative operational costs were based on major electrical uses for aeration and were based on an electric rate of $0.079/kWh. Details of the comparative construction and operational cost estimates are included in the Appendix and the summary list below includes additional electrical/I&C costs. The partial construction cost estimate is shown in the table below.

Table 15. Estimated Partial Construction Costs for Revised Alternative AS-1R

Unit Process	Estimated Partial Construction Costs
Activated Sludge Reactors (7.5 MG in step-feed configuration*)	$19.375 M
Additional Reactor Influent Piping	$0.4 M
Additional Blowers and Blower Building (compared with H-2R)	$3.343 M
Comparative Construction Cost	$23.118 M

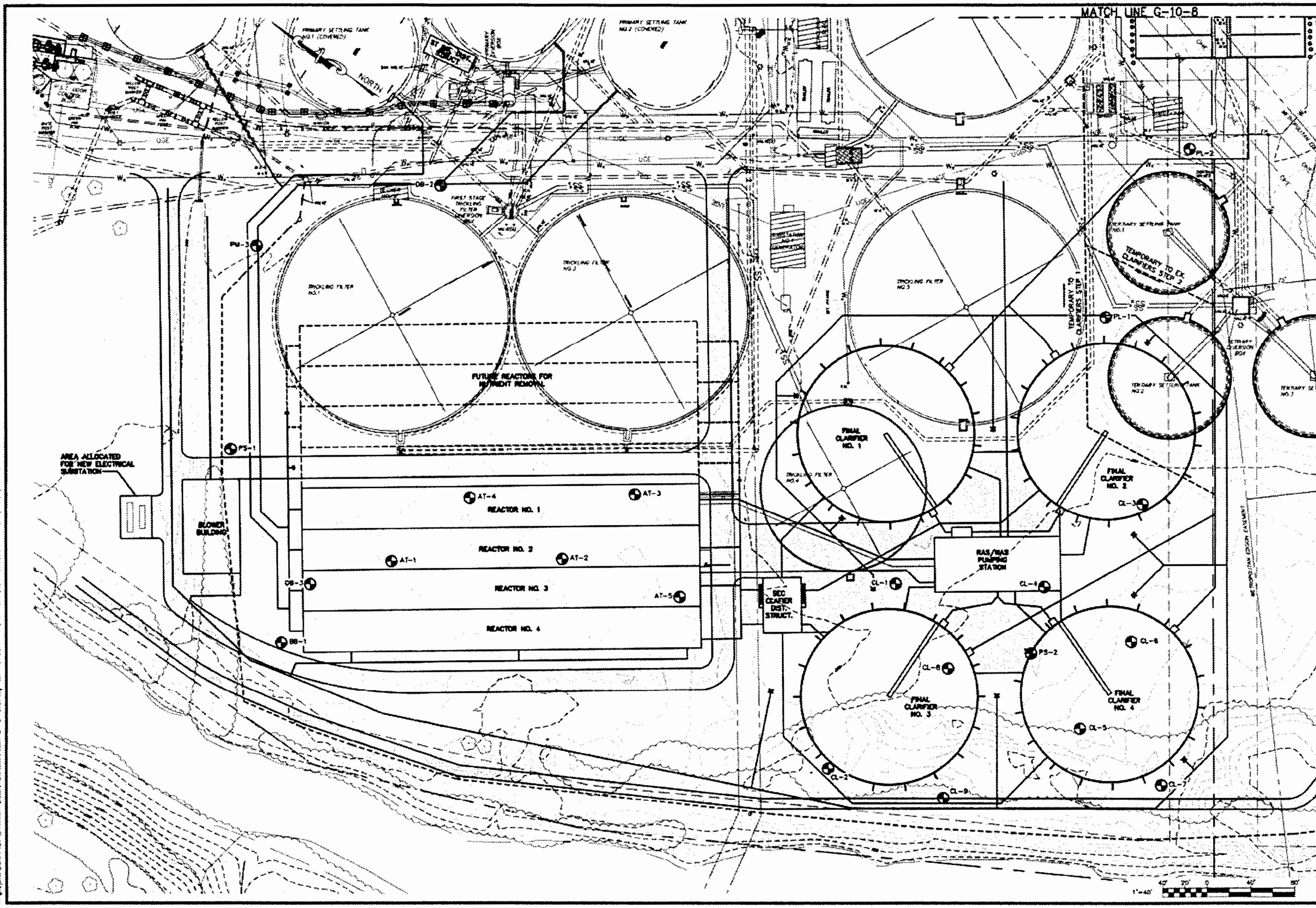
*Construction cost estimate based on 7.5 MG in five reactor basins (1.5 MG each), which was later updated to four reactor basins (1.875 MG each) to minimize construction costs.

The estimated 20-year present worth of the partial operational costs are shown in the table below.

Table 16. Estimated Present Worth of Partial Operational Costs for Revised Alternative AS-1R

Unit Process	Estimated Present Worth of Operation Costs
Aeration electrical cost	$13.668 M

The total partial present worth (construction and operational) for Alternative AS-1R is $36.786 M.



RK&K

RUMMEL, KLEPPER & KAHL, LLP
3501 CONCORD ROAD
SUITE 100
YORK, PENNSYLVANIA 17402

NO	DESCRIPTION	BY	DATE
REVISIONS			

CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP
BERKS COUNTY PENNSYLVANIA

SITE PLAN AS-1R

ENGINEER	DESIGNED BY
DPB	RJA
DRAWN BY	DATE
SEB	12/2013
PROJECT NUMBER	
213-054	

DRAWING NUMBER
FIGURE 10
SHEET NO. OF X

SECTION 6. COST COMPARISON AND COST SENSITIVITY ANALYSES

A comparison of the estimated partial construction costs and the partial present worth costs of the revised Alternatives H2-R and AS-1R is summarized in the table below. Based on the comparison, RK&K recommended Alternative AS-1R be considered for implementation.

Table 17. Comparison of Costs for Revised Alternatives H-2R and AS-1R

	Revised Alternative H2-R	Revised Alternative AS-1R
Estimated partial construction costs	$44.19 M (Chamber snail removal) $48.03 M (Vortex snail removal)	$23.12 M
Estimated partial present worth costs	$54.8 (Chamber snail removal) $59.3 M (Vortex snail removal)	$36.8 M

Several sensitivity analyses were performed (in conjunction with input from the CM/PM team) to determine if changes in design/cost assumptions would cause Alternative H-2R to be less expensive than Alternative AS-1R. The following sensitivity analyses were performed:

- Reducing the estimated cost of the Trickling Filter Distribution Structure and Intermediate/ Recycle PS
- Reducing the estimated cost of the activated sludge reactors
- Reducing the scope/estimated cost of the TF rehabilitation
- Eliminating the snail removal system
- Calculating O&M costs based on $0.11/kWh to capture potential future rate increases

The reduction in estimated costs by the PM/CM team were based on potential reductions in scope/size of structures, reduced contingency, overhead and profit and unit quantity costs. In each of the sensitivity cases, Alternative AS-1R remained the lowest present worth alternative. Each of the analyses is detailed below and presented in a cumulative manner, to provide the most conservative approach (if all proposed cost modifications were adopted).

Sensitivity Analysis No. 1: Reduce estimated cost of trickling filter distribution structure and Intermediate/Recycle PS.

The PM/CM team suggested evaluating the costs based on a reduced cost for the TF distribution structure and Intermediate/Recycle PS. The reduction for the estimated costs for the Trickling Filter Distribution Structure were based on reduced costs per unit quantity and a reduction in the number of gates/stop logs. The reduction for the estimated costs for the Intermediate/Recycle PS was based on using pumps as double-duty for both forward and recycle flow. Control valves would be used to determine flow direction. The estimated costs proposed by the PM/CM team and resulting overall cost are shown in the table on the following page.

Table 18. Sensitivity Analysis No. 1 – Reduced TF Distribution Structure and Intermediate/Recycle PS for Revised Alternative H-2R

Unit Process	Estimated Construction Costs
Trickling Filter Distribution Structure	*$0.8 M* (formerly $1.874 M)
TF Rehabilitation (including media and rotary distributor replacement, piping/hydraulic expansion, structural repairs)	$13.675 M
Snail Removal System	$6.335 M (vortex system) $2.5 M (chamber system)
Intermediate/Recycle Pumping Station	*$5.0 M* (formerly $10.388 M)
Activated Sludge Reactors (6.0 MG in step-feed configuration)	$15.755 M
Comparative Construction Cost	*$41.565 M* (formerly $48.027 M - vortex system) *$37.73 M* (formerly $44.192 M -chamber system)

Both the chamber and vortex grit removal system options for Alternative H-2R remained significantly more expensive than the proposed AS-1R system ($23.118 M) based on the first sensitivity analysis.

Sensitivity Analysis No. 2: Reduce estimated cost of activated sludge reactors.
The PM/CM team suggested evaluating the costs based on a reduced cost for the activated sludge reactors using reduced unit costs. The costs were decreased for both the H-2R and AS-1R alternatives.

Table 19. Sensitivity Analysis No. 2 – Reduced Activated Sludge Reactor Estimated Construction Costs for H-2R

Unit Process	Estimated Construction Costs
Trickling Filter Distribution Structure	*$0.8 M* (formerly $1.874 M)
TF Rehabilitation (including media and rotary distributor replacement, piping/hydraulic expansion, structural repairs)	$13.675 M
Snail Removal System	$6.335 M (vortex system) $2.5 M (chamber system)
Intermediate/Recycle Pumping Station	*$5.0 M* (formerly $10.388 M)
Activated Sludge Reactors (6.0 MG in step-feed configuration)	*$10. 0 M* (formerly $15.755 M
Comparative Construction Cost	*$35.810 M* (formerly $48.027 M - vortex system) *$31.975 M* (formerly $44.192 M -chamber system)

Table 20. Sensitivity Analysis No. 2 – Reduced Activated Sludge Reactor Estimated Construction Costs for AS-1R

Unit Process	Estimated Construction Costs
Activated Sludge Reactors (7.5 MG in step-feed configuration)	*$13.0 M* (formerly $19.375 M)
Additional Reactor Influent Piping	$0.4 M
Additional Blowers and Blower Building (compared with H-2R)	$3.343 M
Comparative Construction Cost	*$16.743 M* (formerly $23.118 M)

Both the chamber and vortex grit removal system options for Alternative H-2R remained significantly more expensive than the proposed AS-1R system based on the sensitivity analysis.

Sensitivity Analysis No. 3: Reduce estimated cost of trickling filter improvements.
The PM/CM team suggested evaluating the costs based on a reduced cost for the TF improvements. The reduction for the estimated costs was based on reducing the labor estimate for rock removal and media installation, as well as considering that the media costs may decrease below budget estimates based on competitive bidding. The estimated costs proposed by the PM/CM team and resulting overall cost are shown in the table below.

Table 21. Sensitivity Analysis No. 3 – Reduced TF Rehabilitation Costs

Unit Process	Estimated Construction Costs
Trickling Filter Distribution Structure	*$0.8 M* (formerly $1.874 M)
TF Rehabilitation (including media and rotary distributor replacement, piping/hydraulic expansion, structural repairs)	*$9.0 M* (formerly 13.675 M)
Snail Removal System	$6.335 M (vortex system); $2.5 M (chamber system)
Intermediate/Recycle Pumping Station	*$5.0 M* (formerly $10.388 M)
Activated Sludge Reactors (6.0 MG in step-feed configuration)	*$10.0 M* (formerly $15.755 M)
Comparative Construction Cost	*$31.135 M* (formerly $48.027 M - vortex system); *$27.30 M* (formerly $44.192 M - chamber system)

Both the chamber and vortex grit removal system options for Alternative H-2R remained significantly more expensive than the proposed AS-1R system (originally $23.118 M; $16.743 M based on sensitivity analysis No. 2) based on the third level of sensitivity analyses.

Sensitivity Analysis No. 4: Eliminated snail removal facilities from project scope
The PM/CM team suggested evaluating the costs based on eliminating the snail removal facilities from the scope of the project. The estimated costs proposed by the PM/CM team and resulting overall construction and operation cost are shown in the tables on the next page.

Table 22. Sensitivity Analysis No. 4 – Eliminating snail removal facilities from project scope

Unit Process	Estimated Construction Costs
Trickling Filter Distribution Structure	*$0.8 M* (formerly $1.874 M)
TF Rehabilitation (including media and rotary distributor replacement, piping/hydraulic expansion, structural repairs)	*$9.0 M* (formerly 13.675 M)
Snail Removal System	$0 M (formerly $6.335 M - vortex system; $2.5 M - chamber system)
Intermediate/Recycle Pumping Station	*$5.0 M* (formerly $10.388 M)
Activated Sludge Reactors (6.0 MG in step-feed configuration)	*$10.0 M* (formerly $15.755 M)
Comparative Construction Cost	*$24.8 M* (formerly $48.027 M - vortex system; $44.192 M - chamber system)

Alternative H-2R remained significantly more expensive than the proposed AS-1R system (originally $23.118 M) based on the fourth level of sensitivity analyses.

Table 23. Sensitivity Analysis No. 4 – Eliminating snail removal facilities from project scope - comparative estimated present worth of operational costs for Alternative H-2R

Unit Process	Estimated Present Worth of Operation Costs
Aeration electrical cost	$7.707 M
Forward flow pumping electrical cost	$0.882 M
TF recycle flow pumping electrical cost	$1.841 M
Snail removal system operational electrical cost (no disposal costs included)	*$0 M* (formerly $0.850 M - vortex system; $0.143 M - chamber system)
Comparative Present Worth Cost	*$10.43 M* (formerly $11.281 M - vortex system; $10.574 M - chamber system)

The total comparative present worth (construction and operational) for Alternative H-2R is based on the fourth sensitivity analysis is $35.23 M, which is higher than the comparative present worth for AS-1R ($30.411 M based on the reduced reactor cost estimate for Sensitivity Analysis No. 2; $36.786 M originally).

Sensitivity Analysis No. 5: Increased power costs

The PM/CM team suggested evaluating the costs based on increased power costs from $0.079/kWh to $0.11/kWh. The estimated present worth of the increased operation costs for both alternatives and total comparative present worth are shown on the following page.

Table 24. Sensitivity Analysis No. 5 – Increased Power Costs

	Alternative H-2R	Alternative AS-1R
Comparative Construction Cost Estimate (based on Sensitivity Analyses 1-4)	$24.8 M	$16.743 M
Present worth of comparative operation costs based on $0.11/kWh	$14.523 M	$19.032 M
Comparative total present worth costs	$39.323 M	$35.775 M

Through each iteration of sensitivity analysis performed, alternative AS-1R remained the lower cost alternative. Details of the sensitivity analyses are in the Appendix.

SECTION 7. DISCUSSION OF ALTERNATIVES FF-1 AND H-1

In addition to Alternatives H-2 and AS-1, the Act 537 Special Study also included an evaluation of Alternatives FF-1 and H-1:

- Alternative FF-1: Rehabilitation of the existing TFs and replacing the rock media and existing synthetic media with new structured media followed by treatment with a new fixed bed biofilm reactor.
- Alternative H-1: Rehabilitation of the TFs, with diversion of a portion of the primary effluent flow directed to the TFs and the remaining portion to new activated sludge reactors. This alternative did not include TF media replacement.

Neither Alternative FF-1 or H-1 were considered for re-evaluation due to the modifications in design basis in consideration of the following:

- Neither FF-1 or H-1 were the lowest cost alternative in the Act 537 Special Study. None of the modifications to the design basis would have caused the costs of these alternatives to decrease relative to AS-1 or H-2. The estimated costs for both alternatives would increase similarly or higher as the estimated costs for H-2R increased due to the following:
  - Both alternatives required TF upgrades, which were found to be relatively costly during preliminary engineering.
  - Both alternatives would require snail removal facilities due to re-use of the TFs. The need for this facility was not captured in the Act 537 Special Study.
  - The required activated sludge reactor for Alternative H-1 was larger than that required for H-2. Due to the increased size of the reactor required to accommodate the additional mixed liquor mass, the size/cost of the reactor associated with H-1 would increase to a greater extent than H-2.
  - The Act 537 Special Study noted that Alternative FF-1 was preliminarily sized "relatively aggressively". The impact of the revised nitrification rate found during RK&K's preliminary design would result in a significantly larger attached growth reactor, which will further increase the cost of this alternative.
- The cost to upgrade Alternative FF-1 for future nutrient removal was estimated to be approximately twice that of the other alternatives in the Act 537 Special Study.
- Non-economic disadvantages of Alternatives H-1 and FF-1 include:
  - Require intermediate pumping
  - Potential odor/snail issues from the TF
  - Potential for less reliable nitrification with FF-1
  - Do not allow full site utilization as compared with Alternative AS-1R (discussed further in the next section.

SECTION 8. NON-ECONOMIC CONSIDERATIONS

In addition to costs, the selection of AS-1R over H-2R was evaluated based on non-economic considerations. The table below provides a summary of the non-economic advantages for each alternative which are discussed further below.

Table 25. Non-Economic Advantages for Alternatives H-2R and AS-1R

Non-Economic Advantages for H-2R	Non-Economic Advantages for AS-1R
No need to revisit Act 537 Special Study	Reduced construction duration
Reduced electrical power usage, especially prior to future BNR implementation	Reduced risk of permit violations during construction
Good settleability in final clarifiers reported in literature	Improved process reliability resulting from no intermediate pumping
	Adaptable to future BNR, eliminates need for de-oxygenation zone
	Eliminates trickling filter problems (snails, worms and potential odors)
	Eliminates cooling effect of trickling filters
	Reduced risk of mercury contaminants by not rehabilitating the trickling filters
	Improved site utilization

Non-economic advantages for H-2R:

- *No need to revisit Act 537 Special Study* – By continuing with the Act 537 Special Study recommended alternative, no administrative project delay would be incurred. Revisiting the Act 537 Special Study (through this Supplemental Report) requires additional engineering work and potential delays to the project. The City and RK&K determined the overall design schedule would be maintained by developing this Supplemental Report concurrently with the BODR. Intermediate design milestones (BODR and the 60% submission) would be delayed, but the final design would be complete by September 30, 2014 as stipulated by the City's project requirements. The revised design schedule is included in the Appendix.
- *Reduced electrical power usage, especially prior to future BNR implementation* – Due to the reduced aeration demand with the TFs, the overall electrical power usage would be less with Alternative H-2R. With future BNR, the aeration demand will decrease due to the denitrification credit and the advantage of Alternative H-2R would decrease.
- *Good settleability in final clarifiers reported in literature* – The coupled trickling filter/activated sludge process is reported in literature to have improved settling characteristics compared with those observed in activated sludge only systems.

Non-economic advantages for AS-1R:

- *Reduced Construction Duration* – Implementing Alternative AS-1R requires a shorter construction duration than implementing Alternative H-2R due to the staged construction required for H-2R. For Alternative H-2R, the activated sludge system must be constructed, tested and put on-line prior to any upgrades to the TFs. Upgrades to the TFs would occur sequentially to allow multiple units to remain in service. Construction of AS-1R will be less time critical because the majority of the activated sludge system can be constructed, tested and put on-line with the only remaining work being demolition of the TFs and construction of a portion of the clarifier system. There are less construction sequencing constraints with the AS-1R alternative.
- *Reduced risk of permit violations during construction* – Construction of the majority of the activated sludge system can occur without interrupting plant operation with Alternative AS-1R. Once the construction of the reactors and a portion of the clarification system is complete, the new activated sludge system can operate with limited risk of effluent permit violations. Due to the reduced clarification capacity until the existing TFs are demolished to allow for the remaining clarifiers to be constructed, existing downstream clarifiers will be used to capture any solids overflows during high flow events during construction. Construction of alternative H-2R would require sequential upgrades of each TF, limiting the treatment capacity during construction.
- *Improved process reliability resulting from (no intermediate pumping* – Alternative AS-1R does not require intermediate pumping. Gravity flow will be provided from the plant influent to effluent discharge. Eliminating the intermediate pumping improves the reliability of the WWTP.
- *Adaptable to future BNR, eliminates need for de-oxygenation zone* – Alternative AS-1R is readily amenable for upgrade to future BNR. The flow pattern does not need to be modified (as compared to the 50% bypass of primary effluent flow around the TFs as required by H-2R) and no de-oxygenation zone is required. The future BNR system will be less complex to operate with Alternative AS-1R.
- *Eliminates trickling filter problems* - The City is well experienced in handling issues associated with TFs, such as snails, worms, odors, and cold weather events. The use of all activated sludge will preclude these issues from occurring which will reduce maintenance requirements.
- *Eliminates cooling effect of trickling filters* – As evidenced by plant data, the TFs provide a cooling effect to the wastewater during winter months. Nitrification is very sensitive at cold temperatures and requires a longer SRT in the activated sludge system to accommodate the slow growing nitrifiers at cold temperatures. Eliminating the TFs will eliminate the cooling effect and allow the activated sludge to operate at a higher wastewater temperature for Alternative AS-1R.
- *Reduced risk of mercury contaminants by not rehabilitating the trickling filters* – The original TF systems utilized mercury to seal the rotary distributor drive. The City has conducted studies to determine if the mercury has contaminated other processes within the facility and has limited

information to determine where the mercury may have migrated. Selective demolition of the TFs will minimize the potential of contamination migration from the units. Proper soil disposal and testing will be provided during demolition of the units.

- *Improved site utilization* – As shown in the proposed site plans for AS-1R and H-2R, alternative AS-1R allows the existing site to be utilized more effectively. It minimizes the impacts on the flood zone adjacent to the Mifflin Arm. It allows for less complicated construction in the final clarifier / RAS PS area. The site layout for AS-1R allows all the reactors to be of similar dimensions and allows sufficient room for the Rifle Range access road to the west of the proposed reactors. The Rifle Range access road will decrease non-WWTP related traffic through the center of the treatment process tankage. The site layout for AS-1R also allows for greater site availability for the future BNR project for chemical storage and feed facilities. Waterway encroachment is anticipated to be reduced for alternative AS-1R compared to H-2R.

SECTION 9. RECOMMENDATION

Based on the present worth costs and non-economic advantages, it is recommended that the City proceed with implementing AS-1R. This Supplemental Report is being provided to document the change in the selected liquid treatment process relative to the recommendation provided in the Act 537 Special Study. The Basis of Design Report (BODR) also includes a summary of the change in selection process and provides details of the proposed AS-1R system.

The revised schedule is included in the Appendix. The full cost estimate for the entire project will be provided in the BODR.

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APPENDIX

5.1.2 Future Permit Criteria

Table 5-7 presents a summary of current, pending and future permit requirements. PADEP has put forth annual mass load limits for the Chesapeake Bay based upon total nitrogen limit (TN) of 6 mg/l and total phosphorus limit (TP) of 0.8 mg/l. The Fritz Island WWTP is not within the Chesapeake Bay; however, there has been a fair amount of discussion of implementing the Chesapeake Bay nutrient limits statewide. The Chesapeake Bay agreement was signed in 2000 and it has taken nearly 10 years to develop the necessary watershed modeling and plans. Subsequently, we would anticipate that the statewide limits of TN of 6 mg/l and TP of 0.8 mg/l would not be implemented until the permit renewal cycle in 2028 at the earliest.

Table 5-7
Anticipated Permit Conditions during Planning Period

	Current Permit		**Pending Permit**		**Nutrient Removal**
Effective Date	Currently In Effect		Upon Completion of WWTP Upgrade		April 1, 2028(1)
	Monthly	Weekly	Monthly	Weekly	Monthly
$cBOD_5$ (Summer), mg/L	20	30	17	27	10
$cBOD_5$ (Winter), mg/L	25	40	25	40	10
TSS, mg/L	30	45	30	45	10
NH_3-N (Summer), mg/L	6		4.5		0.3
NH_3-N (Winter), mg/L	18		13.5		3
TN, mg/L					6
TP, mg/L					0.8

(1) It is anticipated that the statewide limits of TN of 6 mg/l and TP of 0.8 mg/l would not be implemented until the permit renewal cycle of 2028 at the earliest.

Additionally, the USEPA has reviewed the PADEP Watershed Implementation Plan (WIP). The WIP was categorized as severely deficient by the USEPA because it did not adequately address non-point sources. Therefore, the USEPA has commented that if the nutrient discharges from non-point sources are not reduced, then the point sources will be required to provide additional nutrient removal. These additional nutrient removal measures for point sources are presented as two levels of TMDLs: (1) TN = 4 mg/l and TP = 0.3 mg/l or (2) TN = 3 mg/l and TP = 0.1 mg/l. A total phosphorus limit of 0.1 mg/l is unachievable in the colder climates of northern PA and we would expect the PADEP to implement a 0.3 mg/l TP limit. At some

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Del Becker, P.E.
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3501 Concord Road – Suite 100
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August 30, 2013

Dear Mr. Becker:

Re: City of Reading Improvements to the Fritz Island Wastewater Treatment Plant - Wastewater Characterization / Nitrification Kinetics Task Draft Report

On behalf of EnviroSim Associates Ltd., I am pleased to present our report on wastewater characteristics and nitrification kinetics for the City of Reading's Fritz Island Wastewater Treatment Plant. The composition of the influent wastewater and the nitrification rate are crucial components in correctly sizing tankage requirements for the activated sludge component of the treatment plant and as such this information will be important in satisfying the project's main goals.

The report contains information on the specific growth rates of the nitrifying organisms of a lab-scale suspended growth activated sludge system exposed to the Fritz Island plant's raw influent. In addition, estimates of several other wastewater characteristics (*i.e.* soluble / particulate split, biodegradable/non-biodegradable split, *etc.*) for the raw influent have been determined.

The fieldwork portion of this project involved the cooperation and participation of several individuals from the City's laboratory and wastewater treatment plant operating staff. We gratefully acknowledge their contribution to this assignment. Their input has been of considerable help in conducting the project.

Yours truly,

EnviroSim Associates Ltd.

per:

Christopher M. Bye, Ph.D., P.Eng.
Senior Process Engineer

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EXECUTIVE SUMMARY

INTRODUCTION

The City of Reading is replacing its current trickling filter treatment system with a hybrid roughing filter / activated sludge (nitrifying suspended growth) process. In the design of wastewater treatment plants that must remove ammonia, nitrification kinetics and wastewater characteristics are crucial considerations in calculating the tankage requirements (and hence cost) of plant expansions. Experience has shown that nitrification kinetics can vary from plant-to-plant, often due to industrial discharges causing inhibition of the population of nitrifying microorganisms. Therefore to have an increased level of design confidence, it is desirable to measure nitrification kinetics if at all possible; otherwise conservative assumptions must be made which could have significant budget forecasting implications.

The primary objectives of this work were to evaluate the nitrification kinetic parameters (*i.e.* primarily the nitrifier maximum specific growth rates, μ_{AOB} and μ_{NOB}) for a nitrifying activated sludge system treating the Fritz Island WWTP raw wastewater, and to determine the wastewater characteristics of the raw wastewater. This information will be used in sizing the activated sludge process (and related processes) and in developing a BioWin model for the upgraded Fritz Island WWTP expansion.

APPROACH

The approach used to estimate the wastewater characteristics and nitrification kinetics of the Fritz Island wastewater generally followed the low F:M procedure presented in the Water Environment Research Foundation wastewater characterization report (WERF, 2003). The low F:M protocol involves operating a bench-scale sequencing batch reactor (SBR) for several weeks to attain a *quasi* steady-state, and then conducting intensive monitoring over a period of approximately two weeks. Key information derived from the present study is presented in Tables 1 through 3.

CONCLUSIONS

Important conclusions/observations from the study are listed below:

- The raw influent strength is high. The average COD over the 47-day system start-up period was 822 mg/L; the average COD over the 11-day intensive monitoring period was 732 mg/L.
- The raw influent appears to be more soluble in nature than a typical municipal wastewater. This is supported by the following observations:
    - The amount of solids in the wastewater was low relative to the organic strength. The TSS/COD ratio was 0.29 mg TSS / mg COD over the 47-day system start-up and 0.27 mg TSS / mg COD over the 11-day intensive

monitoring period. This ratio is usually around 0.50 mg TSS /mg COD for a typical raw municipal wastewater.

  - The ratio of glass-fibre filtered COD to total COD was 0.61 mg COD / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.40 mg COD / mg COD for a typical raw municipal wastewater.
  - The ratio of flocculated/filtered COD to total COD was 0.47 mg COD / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.25 mg COD / mg COD for a typical raw municipal wastewater.
  - The soluble readily biodegradable fraction of the influent was 0.21 mg COD / mg COD, which is higher than the typical value of 0.16 mg COD / mg COD for a raw municipal wastewater.

- The nutrient content of the wastewater is low relative to the organic strength. This is supported by the following observations:
  - The influent TKN to COD ratio was 0.05 mg N / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.10 mg N / mg COD for a typical raw municipal wastewater.
  - The influent total phosphorus to COD ratio was 0.007 mg P / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.02 mg P / mg COD for a typical raw municipal wastewater.

- The unbiodegradable particulate fraction of the influent total COD (f_{UP}) is 0.10 mg COD / mg COD. This value is lower than the typical value of 0.13 mg COD / mg COD for a raw municipal wastewater and is in fact close to the typical value of 0.08 mg COD / mg COD for a primary settled wastewater.

- Sludge production for the bench-scale activated sludge system operated on Fritz Island raw wastewater was observed to be typical at the estimated SRT of 9.74 d and f_{UP} of 0.10 mg COD / mg COD.

- The nitrification behaviour in the system could be simulated accurately with a μ_{AOB} value of 0.62 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d^{-1}], and a μ_{NOB} value of 0.70 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d-1]. This μ_{AOB} value is lower than the BioWin default value of 0.9 d^{-1} which is based on nitrification rate tests conducted at numerous North American plants. The observed μ_{AOB} value of 0.62 d^{-1} suggests that the ammonia oxidizing bacteria (AOB) were inhibited in the current study.

Tables 1, 2 and 3 below summarize key findings from this study.

Table 1 **Summary of Key Influent Characteristics**

Parameter	Fritz Island WWTP	Typical Raw Influent Value	Typical Primary Settled Influent Value	Units
f_{BS} Fraction of total influent COD that is soluble readily biodegradable	**0.21**	0.16	0.27	mg COD / mg COD
f_{US} Fraction of total influent COD that is soluble unbiodegradable	**0.05**	0.05	0.08	mg COD / mg COD
f_{UP} Fraction of total influent COD that is particulate unbiodegradable	**0.10**	0.13	0.08	mg COD / mg COD
f_{XSP} Particulate fraction of influent slowly biodegradable COD	**0.50**	0.75	0.5	mg COD / mg COD
f_{NA} Fraction of influent TKN that is ammonia	**0.60**	0.66	0.75	mg N / mg N
f_{NUS} Fraction of influent TKN that is soluble unbiodegradable	**0.03**	0.02	0.02	mg N / mg N
f_{NOX} Fraction of influent TKN that is particulate organic	**0.50**	0.50	0.25	mg N / mg N
f_{PO4} Fraction of influent TP that is soluble phosphate	**0.43**	0.5	0.75	mg P / mg P
$f_{N,ML}$ Nitrogen content of sludge	**0.09**	0.10	0.10	mg N / mg VSS
$f_{CV,XS}$ Particulate biodegradable COD/VSS ratio	**1.40**	1.60	1.60	mg COD / mg VSS
$f_{CV,XI}$ Particulate inert COD/VSS ratio	**1.60**	1.60	1.60	mg COD / mg VSS

Table 2 Summary of Ammonia Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{AOB,20}$ Ammonia oxidizing bacteria maximum specific growth rate	**0.62**	0.90	d^{-1}
$b_{AOB,20}$ Ammonia oxidizing bacteria aerobic decay rate	**0.17**	0.17	d^{-1}
$K_{S,AOB,NH4,20}$ Ammonia oxidizing bacteria substrate half-saturation constant (BioWin default, based on WERF, 2003)	**0.70**	0.70	mg N / L
$\Theta\mu_{AOB}$ Ammonia oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default, based on WERF, 2003)	**1.072**	1.072	
$\Theta\ b_{AOB}$ Ammonia oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	**1.029**	1.029	

Table 3 Summary of Nitrite Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{NOB,20}$ Nitrite oxidizing bacteria maximum specific growth rate	**0.70**	0.70	d^{-1}
$b_{NOB,20}$ Nitrite oxidizing bacteria aerobic decay rate	**0.17**	0.17	d^{-1}
$K_{S,NOB,NO2,20}$ Nitrite oxidizing bacteria substrate half-saturation constant (BioWin default)	**0.1**	0.1	mg N / L
$\Theta\mu_{NOB}$ Nitrite oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default)	**1.06**	1.06	
$\Theta\ b_{NOB}$ Nitrite oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	**1.029**	1.029	

CHAPTER 1
INTRODUCTION

1.1 BACKGROUND

The City of Reading is replacing its current trickling filter treatment system with a hybrid roughing filter / activated sludge (nitrifying suspended growth) process. In the future, the activated sludge system will also incorporate biological nutrient removal. In the design of wastewater treatment plants that must remove ammonia, nitrification kinetics and wastewater characteristics are crucial considerations in calculating the tankage requirements (and hence cost) of plant expansions. Experience has shown that nitrification kinetics can vary from plant-to-plant, often due to industrial discharges causing inhibition of the population of nitrifying microorganisms. Therefore to have an increased level of design confidence it is desirable to measure nitrification kinetics if at all possible; otherwise conservative assumptions must be made which could have significant budget forecasting implications.

1.2 OBJECTIVES

The objectives of this work were to:

1. Estimate the nitrification kinetics for the Fritz Island WWTP.

2. Estimate the wastewater characteristics of the Fritz Island raw influent (*e.g.* soluble/particulate split, biodegradable/nonbiodegradable split, *etc.*).

1.3 APPROACH

The approach used to estimate the wastewater characteristics and nitrification kinetics of the Fritz Island wastewater generally followed the low F:M procedure presented in the Water Environment Research Foundation report (WERF, 2003). The low F:M protocol involves operating a bench-scale sequencing batch reactor (SBR) for several weeks to attain a *quasi* steady-state, and then conducting intensive monitoring over a period of approximately two weeks. Data from the intensive testing period provide estimates of:

- The nitrifier maximum specific growth rates (μ_{AOB}, μ_{NOB}); and

- A range of wastewater characteristic fractions (*e.g.* unbiodegradable soluble and particulate COD; readily biodegradable COD; unbiodegradable soluble organic nitrogen, *etc.*).

In this study raw wastewater grab samples collected at two off-site locations ("grit" and "6th and Canal") were used as influent feed to a bench-scale SBR unit for a seven-week acclimatization period followed by an eleven-day intensive testing period.

CHAPTER 2
METHODOLOGY

2.1 PREAMBLE

This chapter of the report describes the special equipment used for the testing program, reviews the rationale for selecting the location for the bench-scale SBR unit and the analytical equipment used during the intensive testing period, and describes the protocols used during both the acclimatization and the intensive testing periods.

2.2 EQUIPMENT REQUIREMENTS

Table 2-1 lists the major equipment and supplies used in the testing program. The equipment was assembled from joint resources of the City's wastewater laboratory, RK&K, and EnviroSim Associates Ltd.

Table 2-1 Major Equipment and Supplies Used in the Bench-Scale Testing Program

Ropes, pails, funnels and 20 L plastic carboys for sample collection, transportation and storage	One nominal 10 L volume glass cylindrical vessel for the sequencing batch reactor (SBR) unit
Misc beakers, graduate cylinders, flasks, clamps, test tube holders, spray bottles, distilled water, and similar supplies commonly used in wastewater laboratory programs	Variable speed laboratory mixer for the SBR unit
Portable DO probe and meter	Retort stand and clamps to mount the mixer over the SBR unit
Portable pH probe and meter	Two aquarium air compressors, flexible tubing and diffuser stones to provide aeration in the SBR unit
Continuous data-logging thermometer	Tubing/stopcock for siphoning SBR decant and plastic pail to decant and collect treated effluent from each SBR unit
Eppendorf Research pro Electronic Pipettes: Two @ 0.1-5 mL	Custom-fabricated (by EnviroSim) dissolved oxygen controller, dissolved oxygen concentration data logger
Pall filtration apparatus and vacuum pump	Dissolved Oxygen probe for controller/data logger above
1.5 micron glass fibre filters (Environmental Express F92447MM 47 mm pre-washed filters and F93447VOL 47 mm pre-washed and weighed filters)	Hach series 2000/2500 lab testing unit complete with spectrophotometer and COD/TN digestion block
Protective eye wear, latex gloves, paper towels, garbage bags, and similar supplies commonly used in wastewater field programs	

2.3 LOCATION OF BENCH-SCALE SBR UNIT

The bench-scale SBR unit was initially set up (on June 10th, 2013) in the Operator's Lab, upstairs in the main administration building. At that time, it was noted that the temperature of the room was very warm. RK&K staff purchased and installed a fan in an attempt to moderate the room temperature. On June 14th, an initial dataset of temperatures of the bench-scale unit's mixed liquor were sent to EnviroSim for analysis. It was observed that daily mixed liquor temperatures were reaching peaks of 29°C. This was cause for concern, given that high temperatures can lead to excessive decay of nitrifying organisms. This in turn had the potential to confound the results of the testing. A request to relocate the bench-scale SBR to the air-conditioned laboratory trailers was made, and the unit was relocated by RK&K field staff on June 18th. The bench-scale unit's mixed liquor temperatures showed more reasonable daily peaks of 23-24°C from that point on.

2.4 SAMPLING LOCATION

When conducting a wastewater characterization study it is desirable to avoid collecting in-plant recycle streams since these can significantly impact the estimated wastewater fractionation. At the Fritz Island WWTP, a number of in-plant recycles are returned to / combined with the primary influent. As such, the primary effluent is influenced by these recycles. Because the plant process is changing significantly (*e.g.* new TF media, activated sludge) it is likely that these recycles will change. As such, it was desirable to avoid feeding the bench-scale unit with the current primary effluent since this would lead to collection of information that is not relevant to the new system that is being designed.

In many cases it is possible to avoid in-plant recycles by sampling at a location just upstream of where they are introduced. However, because of the use of force mains in the City of Reading, this was not possible at the Fritz Island WWTP. Discussions with City staff indicated that of the total plant flow, approximately 80% comes to the plant *via* the "6th and Canal" pumping station; the other 20% comes *via* the "grit" station adjacent to the main plant site.

The bench-scale unit requires a daily feed volume of 8 L. Additional feed also is required for conducting a number of analyses (*e.g.* CODs, solids, TN). Therefore, the following procedure was adopted for influent collection:

- At approximately the same time each day, an 8 L grab sample of wastewater was collected using the installed samplers at the "6th and Canal" pumping station.
- At approximately the same time each day, a 2 L grab sample of wastewater was collected using the installed samplers at the "grit" pumping station.
- These two volumes were combined to make up a 10L sample of feedstock for the bench-scale reactor. Of this influent sample, 8 L was used to feed the bench-scale reactor; the remaining 2 L was used for conducting the various daily analyses.

2.5 DESCRIPTION OF DAILY SBR CYCLE

In the protocol for wastewater characterization, a single cycle in SBR operation consists of five operating modes or periods. The periods are fill, react, waste, settle, and draw (decant), in sequence. The sequence in a cycle is illustrated in Table 2-2. The SBR is operated on the basis of a 24 hour cycle, with a selected maximum volume (V_P). The volume of decant (effluent) withdrawn after the settle period is equal to the volume of wastewater added at each cycle (V_{WW}), less that wasted (q_W).

At start up, the system should be seeded with a mass of microorganisms from an activated sludge system. For this study, mixed liquor from the nearby Wyomissing WWTP was used to seed the SBR. Following start up, quasi steady-state conditions were achieved by repeating the following 24 hour cycle of actions over a period of approximately 3 sludge ages:

1. At the start of each cycle, a fixed volume of wastewater (V_{WW}) of a specified COD concentration ($COD_{T,INF}$) was added to the reactor (FILL).
2. After the "instantaneous" fill, the contents of the reactor were aerated and mixed for a period of 23 hours (REACT). At this point, any liquid volume lost through evaporation was replaced with distilled, de-ionized water.
3. At the end of the react period, while the unit was still fully mixed, a fixed volume (q_W) of mixed liquor was wasted from the reactor to maintain a constant sludge age for the system (WASTAGE). For example, to maintain a 16 day sludge age, 1/16th of the reactor volume (10 L / 16 = 0.625 L) was wasted directly from the reactor. The mixed liquor wastage provided sample volumes for analysis.
4. After wastage, the air supply and mixer were turned off and the sludge was allowed to settle for a period of approximately 45 minutes (SETTLE).
5. At the end of the settle period, the treated effluent (decant) was withdrawn from the reactor (DECANT), leaving the settled sludge at the bottom of the reactor. The volume of supernatant drawn off is equal to the volume of wastewater added initially, less the volume of mixed liquor wasted ($V_{WW} - q_W$).

The SBR in this study was operated for the following conditions:

V_P = 10 L

V_{WW} = 8 L

q_W = 0.625 L/d

SRT = 10L/0.625 L/d = 16 days

After start-up on June 10th, 2013, the system was operated for a period of 47 days (≈3 sludge ages[1]) to attain a quasi steady-state operating condition. On July 29th, 2013, an intensive daily monitoring schedule commenced for a period of 11 consecutive days. Analyses were conducted on samples of influent, waste mixed liquor and decant.

[1] Although the target SRT was 16 days, the *actual* SRT would have been lower (≈10 days) due to some additional solids lost each day in the decant.

In addition to the above daily testing during the intensive period, on two days profiles of ammonia and nitrite/nitrate concentration were measured over the first 8 to 10 hours of the react period. Analyses were performed on small sample volumes (20 mL) withdrawn from the reactor at intervals of approximately 30 minutes. This provided the data for estimating nitrifier maximum specific growth rates of the ammonia and nitrite oxidizing bacteria (μ_{AOB}, μ_{NOB}).

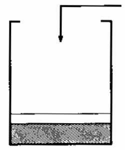
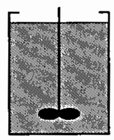
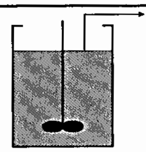
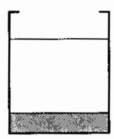
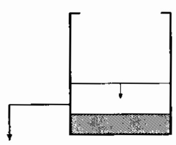
2.6 SELECTION OF SBR SLUDGE AGE

One requirement for the SBR operating procedure is that good solid-liquid separation is achieved during the settle period. Normally it is desirable to run the SBR at a total suspended solids (TSS) concentration in the range of 1200 – 1800 mg/L. Under these circumstances, the sludge should flocculate well and exhibit zone settling behaviour.

In many North American cases the influent COD to the SBR will be in the region of 300-400 mg/L. The SBR receives influent only once per day and the feed volume necessarily is less than the reactor volume, *i.e.,* the effective hydraulic retention time in the SBR exceeds one day. In this situation, with typical wastewater characteristics, the SBR sludge age necessarily should exceed approximately 12 days to obtain the required TSS concentration; hence the selected target SRT of 16 days.

One advantage of operating at a long sludge age is that the unbiodegradable particulate fraction of the VSS becomes more significant as the sludge age increases. As a result, determination of the influent unbiodegradable particulate COD fraction should be more accurate than that determined at a shorter sludge age. A second advantage is that nitrification in the SBR likely will be achieved and should be stable at the long SRT.

Table 2-2 **Bench-Scale SBR Operating Conditions**

PHASE	TIME	REACTOR CONDITION	ACTION
FILL	T = 0 (Instantaneous fill)		V_{WW} of wastewater is added to reactor containing V_P - V_{WW} of mixed liquor, i.e. reactor is filled to the maximum volume (V_P).
REACT	T = 0 – 23 hours		Reactor volume constant (V_P). Mixing and aeration on.
WASTE	T = 23 hours (Instantaneous wastage)		Mixing and aeration on. Withdraw volume of mixed liquor for wastage (q_W). $q_W = V_P/SRT$.
SETTLE	T = 23 - 23¾ hours		No mixing or aeration. Allow sludge to settle.
DRAW	T = 23¾ - 24 hours (Instantaneous draw of treated water)		No mixing or aeration. Decant off supernatant (effluent) volume of (V_{WW} - q_W), leaving a volume of $V_P - V_{WW}$ in the reactor.
Parameters for this study: V_P = 10 L,	V_{WW} = 8 L, q_W = 0.625 L (i.e. SRT = 10/0.625 = 16 days)		

2.7 DAILY MAINTENANCE OF THE SBR UNIT

The daily program for the care and feeding of the bench-scale SBR unit throughout the acclimatization and intensive testing periods was as follows:

1. **Sample collection and storage:** Raw influent grab samples were collected at the two off-site locations discussed above. Grab sample collection occurred at approximately 0830 h each day, seven days per week.
2. **Record Temperature & OUR:** The temperature and OUR data for the unit were recorded continuously throughout the study period using a thermometer and a DO probe each connected to a logger.
3. **Re-Suspension of Wall Growths:** Between the daily morning maintenance periods on the bench-scale unit, a certain amount of biomass would accumulate on the walls of the SBR, the mixing impeller, *etc.* This material was dislodged and re-suspended into the mixed liquor by gently scraping it from the surfaces with a soft spatula.

4. **Topping-Up the SBR:** Between daily feedings of the SBR, some evaporation of water occurred due to the constant mixing and aeration. To compensate for this phenomenon, distilled water was used to top-up the SBR to the desired liquid volume.
5. **Collection of Waste Activated Sludge (WAS) Sample:** A soup ladle was used to withdraw a waste sample from the SBR unit. The volume of WAS sample withdrawn from the SBR was calculated to achieve a target 16 day SRT. A 1,000 mL graduated cylinder was used in conjunction with the soup ladle to obtain the correct WAS volume.
6. **Mixed Liquor Settling Phase:** Having collected the WAS sample, the mixer and aeration devices were shut off and the mixed liquor was allowed to settle for a period of 45 minutes.
7. **Treated Effluent Decanting:** Flexible tubing with a stopcock attached to one end was primed with tap water and carefully inserted to a point above the settled sludge blanket. The tubing was clamped to the side of the SBR so that the stopcock could be opened and the priming liquid could be discharged to a discard bucket. The remainder of the decant was then collected in a pail so that a sample of it could be collected for analysis. The decanting operation took approximately 10 minutes.
8. **Re-Filling the SBR:** After decanting the effluent, the SBR was refilled to the prescribed fill mark with a well-mixed volume of the raw wastewater sample and the mixing and aeration devices re-started.

Sub-samples of the raw influent, WAS, and decant streams were taken three days per week (Monday, Wednesday, Friday) for analysis. Table 2-3 presents the sampling and analytical schedule for the acclimatization period.

Table 2-3 **Sampling & Analysis Schedule During the Acclimatization Period**

SAMPLE	TOTAL COD	NH_3-N	TSS	NO_X-N
Raw Influent	√	√	√	-
Waste Activated Sludge	-	-	√	-
Decant	-	-	√	√

2.8 INTENSIVE TESTING PROGRAM PROCEDURES

Intensive monitoring of the SBR was performed for a period of 11 days starting with the influent feed on July 29th, and terminating with the decant on August 9th, 2013. [Note: Decant and WAS on day X is referenced to the feed on day (X-1); *e.g.* decant on August 9th is referenced to the feed on August 8th].

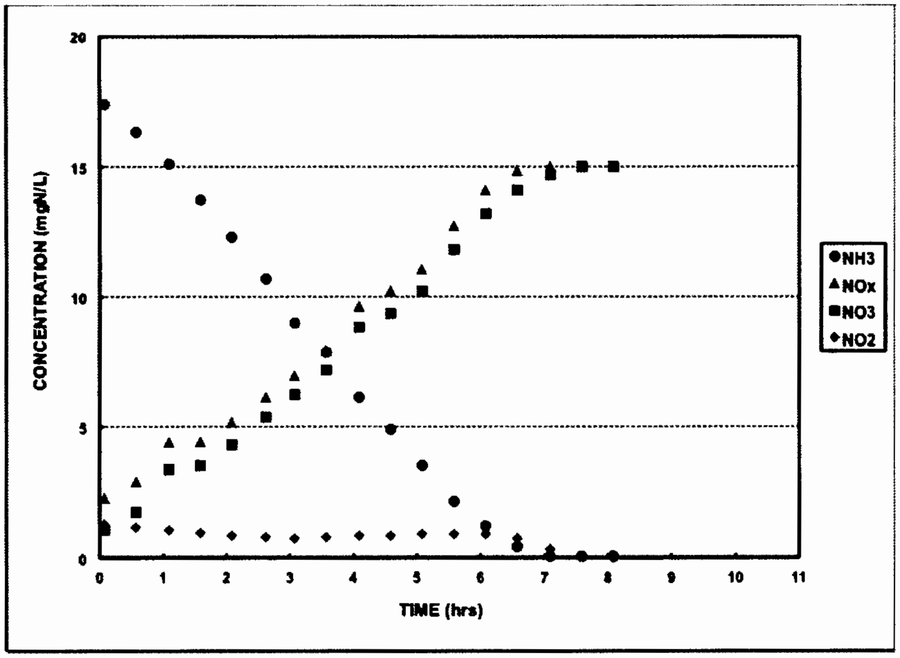
Table 2-4 lists the daily analyses performed on the SBR. Analyses were performed by EnviroSim personnel in the City's lab facility. The number in parentheses following each analysis performed by EnviroSim staff represents the number of replicates performed for each (*e.g.* "2" indicates analysis done in duplicate, "3" indicates analysis done in triplicate).

Table 2-4 Sampling & Analysis Schedule During the Intensive Monitoring Period

SBR Stream	Parameter Monitored	Symbol in Tables
Influent	TSS (3)	TSS
	VSS (3)	VSS
	Total COD (3)	COD tot.
	Glass fibre filtered COD (on VSS/TSS filtrate) (2)	COD gf filt.
	Flocculated & filtered COD (ffCOD) (2)	COD ff
	Total Phosphorus (2)	TP tot.
	Total Nitrogen (3)	TN tot.
	Soluble reactive phosphorus (2)	PO4-P
	Ammonia-N (2)	NH3
	Nitrate-N (1)	NO3
WAS	TSS (3)	TSS
	VSS (3)	VSS
	Total COD (3)	COD tot.
	Total Nitrogen (3)	TN tot.
	Oxygen Utilization Rate	-
	Temperature	-
Decant	TSS (2)	TSS
	VSS (2)	VSS
	Total COD (2)	COD tot.
	Glass fibre filtered COD (on VSS/TSS filtrate) (2)	COD gf
	Flocculated & filtered COD (ffCOD) (2)	COD ff
	Glass fibre filtered COD (on VSS/TSS filtrate) Total Nitrogen (2)	TN gf
	Ammonia-N (2)	NH3
	Nitrite-N (2)	NO2
	Nitrate-N (2)	NO3

On two days during the intensive monitoring period of SBR operation, profiles of ammonia, nitrite, and nitrate concentration were monitored over the first 8 to 10 hours of the reaction period immediately following feeding of the bench-scale unit. Analyses were performed on small sample volumes (20 mL) withdrawn from the reactor (and filtered immediately) at 30 minute intervals. An example of such a profile is shown in Figure 2-1.

Figure 2-1 **Example of an Ammonia/NO_X Profile**



2.9 ANALYSIS OF RESULTS

Results gathered during the intensive monitoring period were used to derive a range of influent wastewater characteristic parameters and estimate the nitrifier maximum specific growth rates (μ_{AOB}, μ_{NOB}). Certain of the wastewater characteristics can be calculated from direct measurements; these include:

Influent soluble unbiodegradable COD fraction (f_{US}):

The influent soluble unbiodegradable COD fraction is estimated directly from measured data as follows:

$$f_{US} = \frac{\text{Effluent ffCOD}}{\text{Unfiltered Influent COD}} \tag{2.1}$$

Influent readily biodegradable COD fraction (f_{BS}):

The readily biodegradable COD fraction is estimated directly from measured flocculated and filtered COD (ffCOD) data as follows:

$$f_{BS} = \frac{\text{Influent ffCOD - Effluent ffCOD}}{\text{Unfiltered Influent COD}} \tag{2.2}$$

The f_{BS} value estimated by equation (2.2) should be confirmed by simulating the system. Responses such as the predicted and measured ammonia removal and OUR profiles should show good matching. The readily biodegradable COD in municipal wastewaters is presumed to consist of relatively small particles which can be easily transported into the cell, while the slowly biodegradable COD is assumed to consist of larger and more complex colloidal and particulate material which requires extracellular breakdown prior to uptake and utilization (WERF, 2003). This inferred parallel between the biokinetic division and the division based on physical characteristics appears to offer a basis for measuring f_{BS} by physical separation and COD measurement. However, this parallel will not necessarily be true for industrial wastewaters that may have a large number of soluble compounds with a wide range of biodegradation rates. Discussion on the simulation verification of f_{BS} can be found in Section 4.6.

Ammonia fraction of the influent TKN (f_{NA}):

The fraction of the total influent TKN that is free and saline ammonia is estimated directly as:

$$f_{NA} = \frac{\text{Influent NH}_3\text{ - N}}{\text{Unfiltered Influent TKN}}$$
$$= \frac{\text{Influent NH}_3\text{ - N}}{\text{Unfiltered Influent TN - Influent NO}_3} \qquad (2.3)$$

Soluble unbiodegradable fraction of the influent TKN (f_{NUS}):

The soluble unbiodegradable fraction of the influent TKN can only be *estimated* based on the filtered effluent TKN (or TN) and ammonia concentrations from a fully-nitrifying activated sludge system; it cannot be directly measured. In the case of the SBR for this study, the filtered effluent TN is comprised of nitrate (NO_3), nitrite (NO_2), a small amount of residual ammonia (NH_3-N), a small amount of residual (yet-to-be-converted-to-ammonia) soluble biodegradable organic nitrogen (N_{OS}), and any soluble unbiodegradable organic nitrogen (N_{US}) from the influent:

$$\text{Filtered effluent TN} = NO_2 + NO_3 + NH_3 + N_{OS} + N_{US} \qquad (2.4)$$

The difference between the filtered TN and the sum of ammonia, nitrite, and nitrate concentrations will be the sum of soluble biodegradable and unbiodegradable organic nitrogen (N_{OS} and N_{US}, respectively). For a fully-nitrifying system, usually the ammonia concentration will be low, say 0.1 mgN/L. Model applications indicate that the residual concentration of *biodegradable* organic nitrogen (*i.e.* material which has not been converted to ammonia) in the effluent typically is about 0.5 – 1.0 mgN/L. Based on these assumptions, the unbiodegradable soluble nitrogen can be estimated as follows:

$$N_{US} \approx Filtered\ effluent\ TN - NO_2 - NO_3 - NH_3 - 0.5\ mgN/L$$

$$f_{NUS} = \frac{N_{US}}{TN} \tag{2.5}$$

Phosphate fraction of the influent TP (f_{PO4}):

The fraction of the influent TP that is phosphate is:

$$f_{PO4} = \frac{\text{Influent } PO_4 \text{ - P}}{\text{Unfiltered Influent TP}} \tag{2.6}$$

The parameters listed above are characteristics of the influent wastewater that are specifically required as model input information for applying the BioWin™ simulator. It is useful to calculate a number of other parameters based on the monitored data as a means of assessing data quality; these include:

Mixed liquor inorganic suspended solids concentration (ISS):

The concentration of inorganic suspended solids (ISS) in the mixed liquor is the difference between the total and volatile suspended solids concentrations:

$$ISS_{ML} = TSS - VSS \tag{2.7}$$

Mixed liquor COD/VSS ratio ($f_{CV,ML}$):

The mixed liquor COD/VSS ratio is a composite determined by the COD/VSS ratios of biomass, unbiodegradable solids from the influent, *etc.* Typically the observed value is approximately 1.48 mg COD / mg VSS for sludge withdrawn from a system treating municipal wastewater:

$$COD/VSS = \frac{\text{ML Unfiltered COD - ML GF COD}}{\text{Mixed Liquor VSS}} \tag{2.8}$$

The mixed liquor filtered COD should be closely equal to the effluent filtered COD, so that the ratio can also be calculated as follows:

$$COD/VSS = \frac{\text{ML Unfiltered COD - Effluent GF COD}}{\text{Mixed Liquor VSS}} \tag{2.9}$$

Mixed liquor nitrogen content ($f_{N,ML}$):

$$N/VSS = \frac{\text{ML Unfiltered TN - Effluent GF TN}}{\text{Mixed Liquor VSS}} \tag{2.10}$$

Influent TKN/COD ratio:

$$TKN/COD = \frac{\text{Unfiltered Influent TKN}}{\text{Unfiltered Influent COD}}$$
$$= \frac{\text{Unfiltered Influent TN - Influent } NO_3}{\text{Unfiltered Influent COD}} \tag{2.11}$$

Influent glass fibre filtrate COD/ total COD fraction:

$$CODgf/COD = \frac{\text{Influent GF filtrate COD}}{\text{Unfiltered Influent COD}} \tag{2.12}$$

Influent ffCOD/ total COD fraction:

$$ffCOD/COD = \frac{\text{Influent ffCOD}}{\text{Unfiltered Influent COD}} \tag{2.13}$$

Influent TSS/COD ratio:

$$TSS/COD = \frac{\text{Influent TSS}}{\text{Unfiltered Influent COD}} \tag{2.14}$$

Influent ISS/TSS ratio:

$$ISS/TSS = \frac{\text{Influent ISS}}{\text{Influent TSS}} \tag{2.15}$$

Influent ISS/COD ratio:

$$ISS/COD = \frac{\text{Influent ISS}}{\text{Unfiltered Influent COD}} \tag{2.16}$$

Influent VSS/TSS ratio:

$$VSS/TSS = \frac{\text{Influent VSS}}{\text{Influent ISS}} \tag{2.17}$$

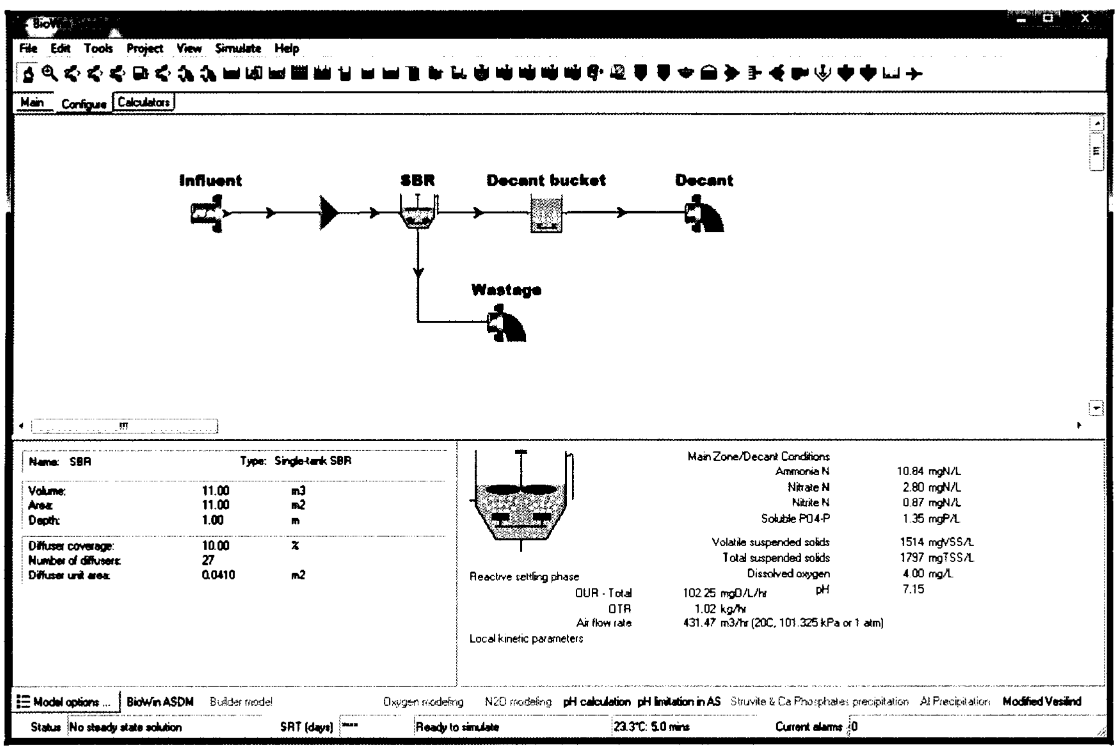
Influent TP/COD ratio:

$$TP/COD = \frac{\text{Unfiltered Influent TP}}{\text{Unfiltered Influent COD}} \tag{2.18}$$

Certain influent wastewater characteristics (and the nitrification rates μ_{AOB} and μ_{NOB}) cannot be determined by direct measurement (or the estimates calculated from direct measurements are not accurate). These include the fraction of the influent COD which is particulate unbiodegradable (f_{UP}) [this parameter is particularly important with respect to estimating sludge production]. This must be estimated iteratively either using an analytical model or through simulation (the latter approach was used in this study). The simulation approach also provides a basis for confirming estimates of certain parameters such as the soluble readily biodegradable influent COD fraction (f_{BS}) and the fraction of the influent TKN which is soluble unbiodegradable (f_{NUS}).

The simulation study of SBR behaviour was conducted to model system response for the SBR over the intensive monitoring period. A screen view of the simulation model interface is shown in Fig. 2-2. Operating conditions such as the influent volume and the various periods in the SBR cycle time are set up in the simulator. The influent COD, TKN and ISS concentrations for each day are specified in the influent element, together with the fractional characteristics determined from the direct measurements. As shown in Fig. 2-2, a variable volume reactor labelled "decant bucket" is used to collect and completely mix each day's decant volume, as was done in practice in the laboratory. This allows for direct comparison of the simulated and measured constituent concentrations in the daily decant volume.

Figure 2-2 Screen View of the SBR Simulation Model



A number of simulation runs are performed, iteratively varying the values of the parameter to be estimated, f_{UP}. The objective is to obtain a reasonable fit of simulated to observed response over the intensive period using a single value for the parameter. In the case of f_{UP}, the primary parameter response to match is VSS concentration.

The maximum specific growth rates of the nitrifiers (μ_{AOB}, μ_{NOB}) are determined in a similar fashion. However, in this case the data to be matched are the responses of ammonia, nitrite, and nitrate over the first 8 to 10 hours of the days of SBR operation where profile data (such as those shown in Figure 2-1) were collected.

2.10 DATA VALIDATION

An important quality control check is to verify the experimental data as far as possible. A number of checks can be applied to the data collected over the intensive monitoring period; these include:

- **Consistency of fractions/ratios:** The SBR is not at a perfect steady-state, and influent concentrations may vary substantially from day to day. Therefore, the values of measured parameters also will vary; for example, changing influent TKN results in changing effluent nitrate from day to day. A useful approach for data validation is to review the daily fractions/ratios calculated from the measured data. Typically these should not vary substantially from day to day. For example, although influent COD and TKN may increase on a given day, one would expect the TKN/COD ratio to remain relatively constant. Examining data fractions and ratios is useful for identifying suspect data, screening outliers, and identifying unusual data.

- **COD mass balance:** If oxygen utilization rate is monitored continuously it is possible to calculate a COD mass balance (*i.e.* output COD / input COD) for each day of operation, and over the whole period of intensive monitoring. This provides an overall validation of the experimental COD data. Typically the daily balances may show some variability due to daily loading changes. However, the overall balance for the whole period of intensive monitoring should be within ± 10% of 100 percent. If not, it is an indication that a problem exists with the experimental data. The basis for calculating the balances is as follows:

$$Daily\ Input = V_{ww} * Influent\ Unfiltered\ COD$$

$$\begin{aligned} Daily\ Output = & \left(V_{ww} - q_w\right) * Decant\ Unfiltered\ COD \\ & + q_w * SBR\ Unfiltered\ COD \\ & + Total\ Mass\ Oxygen\ Utilized\ \left(area\ under\ OUR\ curve\right) \\ & - V_{ww} * Decant\ nitrate\ N * 4.57 \\ & - V_{ww} * Decant\ nitrite\ N * 3.43 \end{aligned}$$

- **Nitrogen mass balance:** A mass balance on nitrogen (*i.e.* output N / input N) can be calculated for each day of operation, and over the whole period of intensive monitoring. This provides an overall validation of the experimental nitrogen data (*e.g.* TKN, TN, NO_3). Typically the daily balances may show some variability due to daily loading changes. However, the overall balance for the whole period of intensive monitoring should be within ± 10% of 100 percent. If not, it is an indication that a problem exists with the experimental nitrogen data. The basis for calculating the balances is as follows:

$$Daily\ Input = V_{ww} * Influent\ TN$$

$$\begin{aligned} Daily\ Output = {} & V_{ww} * Decant\ nitrate\ N \\ & + V_{ww} * Decant\ nitrite\ N \\ & + V_{ww} * Decant\ ammonia\ N \\ & + V_{ww} * Decant\ soluble\ N\ (\mathrm{org} + \mathrm{unbio}) \\ & + (V_{ww} - q_w) * Decant\ VSS * N\ Content\ of\ VSS \\ & + q_w * SBR\ VSS * N\ Content\ of\ VSS \end{aligned}$$

- **Comparison of fractions/ratios to typical/expected values:** A database of information exists on wastewater characteristic fractions/ratios for many different municipal wastewaters (WERF, 2003), and these typically show reasonable consistency from plant to plant. This can be used as a reference for evaluating the new data. In certain cases there may be deviations from "typical" values for good reason (*e.g.* as a result of industrial inputs); however, there should always be evidence to justify deviations.

All of these techniques for data validation were applied during and at the end of the intensive monitoring period. This did not identify any significant problems with the data from Hach and solids analyses conducted by EnviroSim in the City's laboratory.

CHAPTER 3
RESULTS FROM SBR ACCLIMATIZATION PERIOD

3.1 PREAMBLE

This chapter of the report describes the general performance of the bench-scale SBR unit during the acclimatization phase of the work program. Certain of the analytical results from the routine daily sampling program (see Table 2-3) are plotted and reviewed. [Note that some of the plots include data from the intensive monitoring period – July 29th to August 9th, 2013]. The responses of the mixed liquor solids and the treated effluent nitrate-nitrogen concentrations in the bench-scale unit to variations in the carbon and nitrogen contaminant concentrations in the influent feed are noted.

Appendix A contains a number of plots for daily OUR profiles that were collected during the acclimatization phase.

3.2 RAW WASTEWATER COD, TSS, & VSS

Figure 3-1 plots the COD and TSS concentrations in the daily raw wastewater grab samples used to feed the bench-scale SBR unit. The COD concentration of the grab samples collected for feed typically ranged between about 600 to 1,000 mg/L with an overall mean value of 789 mg/L. The TSS concentration showed less variability; for example TSS concentration in the grab samples typically varied from about 200 mg/L to about 400 mg/L with a mean of about 240 mg/L.

Figure 3-2 shows the ratio of TSS to COD for the SBR feed. It is evident from the data that the ratio seems unusually low; typically this ratio is about 0.50 mg TSS / mg COD for a raw municipal wastewater. The overall ratio observed in this study was 0.30 mg TSS / mg COD.

Figure 3-1 COD and TSS Concentrations in Raw Influent Grab Samples Used as Feed for the SBR Unit

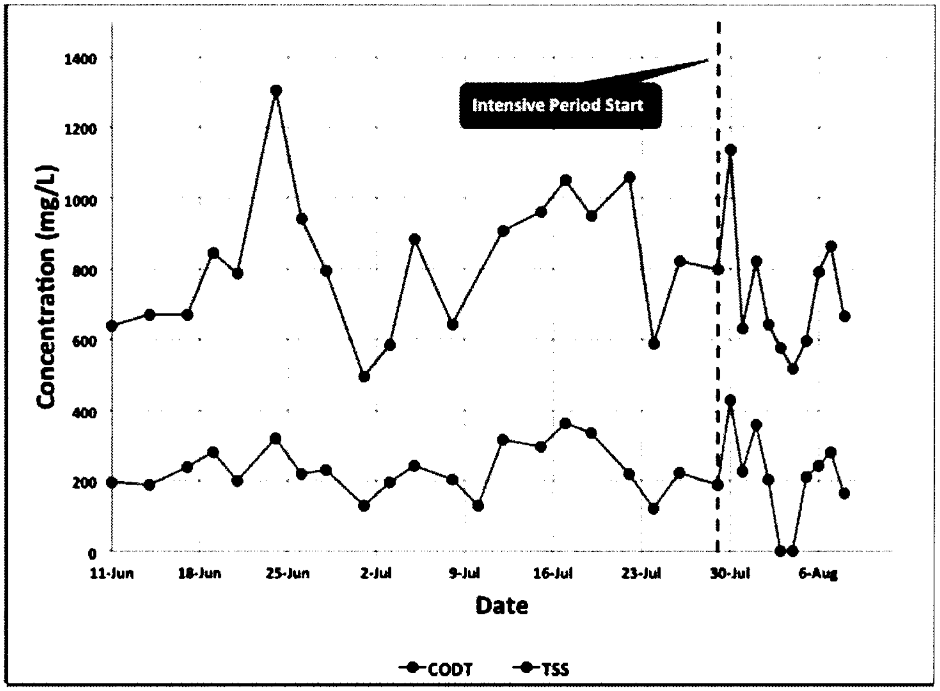
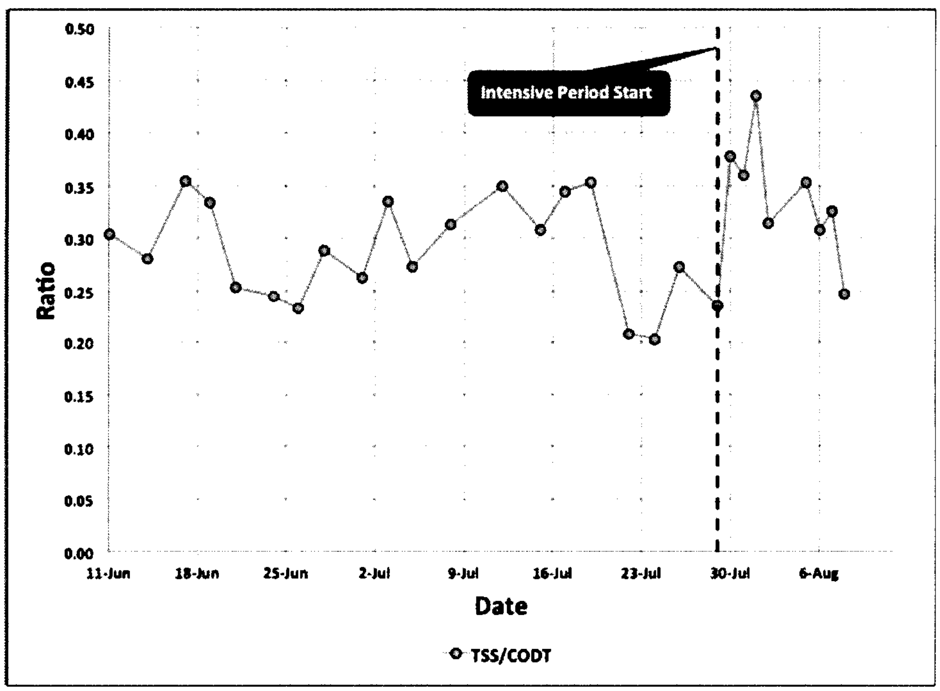


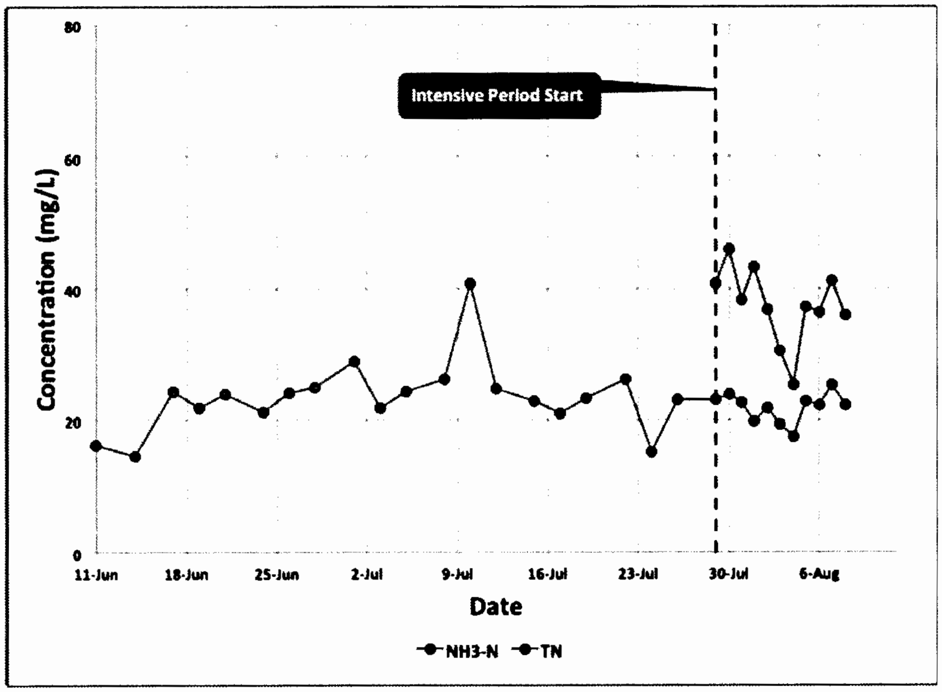
Figure 3-2 TSS:COD Ratio in Raw Influent Grab Samples Used as Feed for the SBR Unit



3.3 RAW WASTEWATER TN & AMMONIA

Figure 3-3 plots the ammonia and TN (for the intensive period only) concentrations in the daily feed used for the bench-scale SBR unit. The ammonia concentration in the grab samples typically varied from about 20 mgN/L to about 30 mgN/L with a mean of about 23 mgN/L. The TN concentration of the grab samples collected for feed typically was close to 40 mgN/L with a mean value of about 37 mgN/L. The consistency of the ammonia throughout the start-up phase suggests that TN levels would have been similar to the intensive period levels had they been monitored throughout start-up.

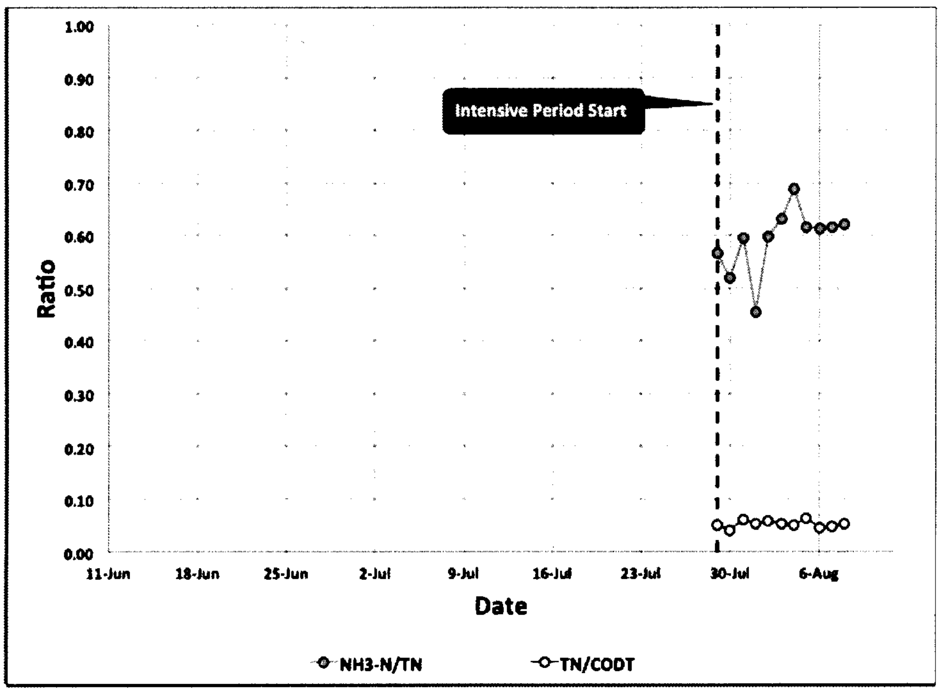
Figure 3-3 TN and Ammonia Concentrations in Raw Influent Grab Samples Used as Feed for the SBR Unit



3.4 RAW WASTEWATER TN RATIOS

Figure 3-4 plots the TN:COD and ammonia:TN ratios in the daily feedstock used for the bench-scale SBR unit. The TN:COD ratio is fairly consistent around 0.05 mg N / mg COD which is significantly lower than the typical municipal wastewater value of 0.10 mg N / mg COD. The TN:COD ratio is an indicator of a plant's denitrification potential; a low TN:COD ratio is favourable for achieving lower effluent nitrate levels since it indicates there is sufficient carbon in the influent wastewater to drive denitrification. The opposite is true for a high TN:COD ratio. The ammonia:TN ratio averaged about 0.60 mg N / mg N which is slightly lower than typical (*e.g.* a typical value is 0.66 mg N / mg N).

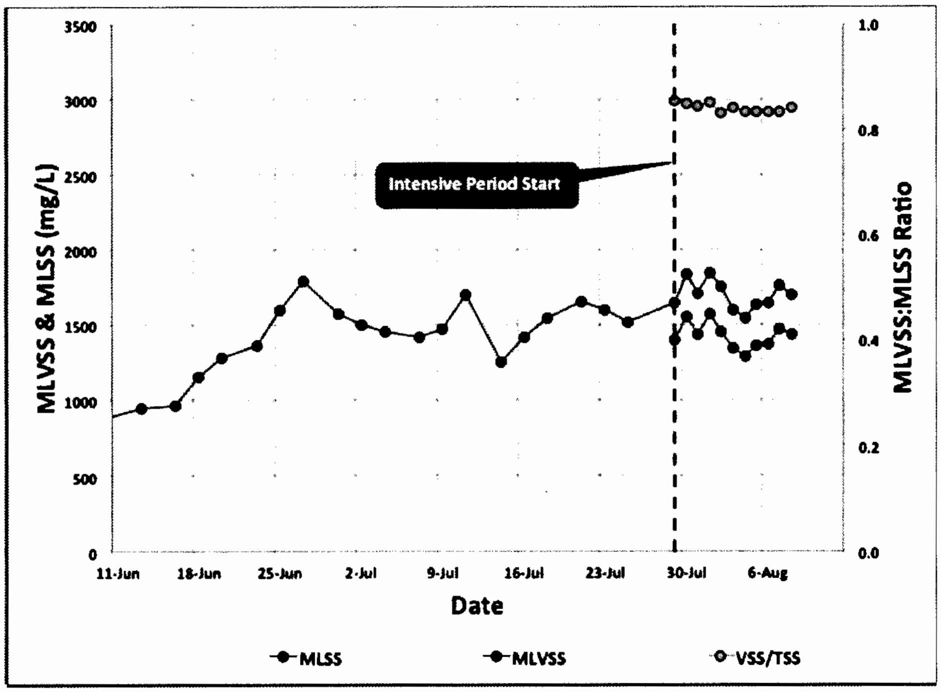
Figure 3-4 TN:COD and Ammonia:TN Ratios in Raw Influent Grab Samples Used as Feed for the SBR Unit



3.4 MIXED LIQUOR SUSPENDED SOLIDS

The MLSS and MLVSS concentrations in the bench-scale SBR unit are plotted in Figure 3-5. After the initial two weeks of operation the MLSS concentration did not vary a great deal. It is worth noting that the MLVSS:MLSS ratio was 0.84. While this value is typical for a conventional activated sludge process treating ***primary-settled*** wastewater, it was somewhat higher than anticipated for mixed liquor withdrawn from a system treating ***raw*** wastewater as was the case in this study. The higher than anticipated ratio is a consequence of the high-strength influent COD and relatively low influent solids concentration.

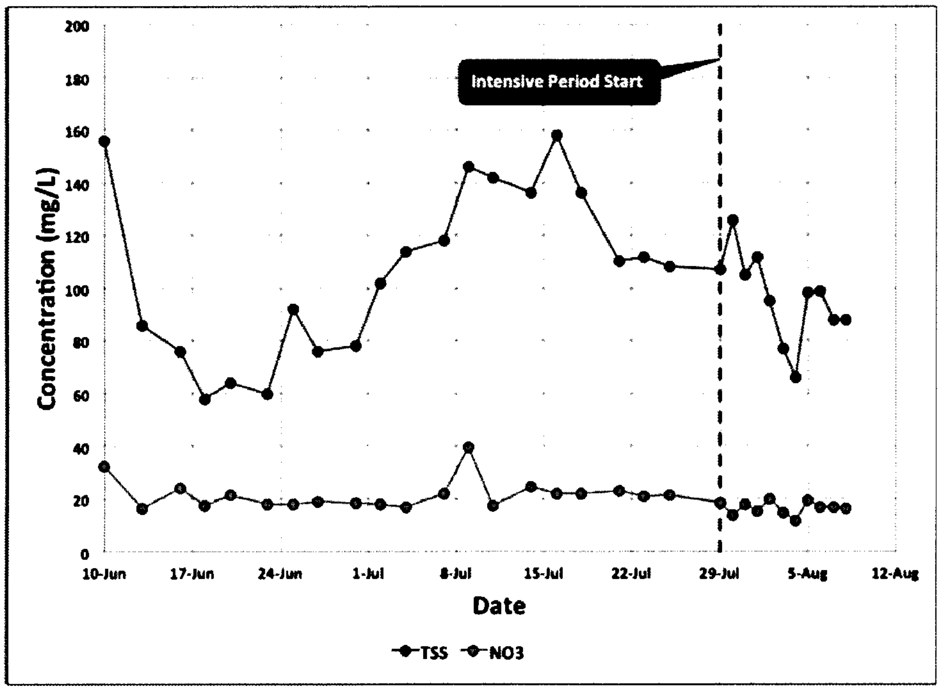
Figure 3-5 Mixed Liquor Concentration in Bench-Scale SBR Unit (note date plotted is Sample Date – 1 to correspond with correct feed sample date, ref. Section 2.7)



3.5 DECANT SOLIDS AND NITRATE

Figure 3-6 shows the treated effluent decant NO_3-N and TSS concentrations in the bench-scale SBR unit. The NO_3-N concentration was quite stable at a mean value of about 20 mgN/L. The decant TSS concentration was higher than desirable; this is a consequence of operating the bench-scale SBR with very intense mixing in an attempt to capture the high oxygen utilization rates associated with the high COD at the start of the SBR feed cycle. However, the decant solids levels are taken into account in all mass balance, sludge production, and simulation analyses so they will not yield spurious results.

Figure 3-6 NO_x-N and TSS Concentrations in Treated Effluent Decant from Bench-Scale SBR Unit (note date plotted is Sample Date – 1 to correspond with correct feedstock date, ref. Section 2.7)



CHAPTER 4
INTENSIVE TESTING PERIOD

4.1 PREAMBLE

This chapter presents the results from analysis of the data gathered during the intensive monitoring period for the bench-scale SBR unit. The methods applied in the analysis were according to the procedures described in Chapter 2.

4.2 MONITORING RESULTS

Results from the 11-day intensive monitoring period are recorded in Tables 4-1, 4-2, and 4-3. The data are divided into three sections, for influent, reactor mixed liquor, and decant (treated effluent). The red dates indicate days where additional sampling of ammonia, nitrate, and nitrite was conducted for estimation of nitrification rates. Averaged values are included for each parameter. In some cases, individual daily values have been removed if these were outliers relative to the overall dataset.

4.3 SBR DATA VALIDATION: MASS BALANCES

Complete nitrogen and COD mass balances were performed on the experimental data from the intensive monitoring period. The results of the mass balance calculations are recorded in Tables 4-4 and 4-5. The COD and nitrogen balances closed to 104% and 92%, respectively, indicating data integrity.

4.4 RELEVANT INFLUENT & MIXED LIQUOR RATIOS

Table 4-6 lists various influent and mixed liquor ratios and fractions for a range of parameters. Again, in a few instances values are missing either because data were not available, or the data used to calculate the values were suspect.

Influent TSS/COD ratio: The overall average value of 0.33 mg TSS / mg COD is lower than typical for raw municipal wastewater. A more typical value would be on the order of 0.5 mg TSS / mg COD. This indicates that the COD of the wastewater is disproportionately higher than the suspended solids content. In calculating the overall average TSS/COD ratio, the TSS/COD ratios on Saturday August 3rd and Sunday August 4th were excluded because they were very low (around 0.15) and therefore considered outliers. The TSS and VSS values on these two days were removed from the dataset for calculation of average concentrations, ratios, and fractions.

Influent TKN/COD ratio: The overall average value of 0.05 mg TKN / mg COD is about half of the typical value for raw municipal wastewater.

Influent TP/COD ratio: The overall average value of 0.007 mg TP / mg COD is lower than the typical value of 0.020 for raw municipal wastewater.

Influent solids VSS/TSS ratio: The average value of 0.86 mg VSS / mg TSS is slightly higher than typical for raw municipal wastewater.

Influent Glass Fibre-filtered COD/Total COD ratio: The overall average value of 0.61 mg COD / mg COD is significantly higher than typical for raw municipal wastewater. This corroborates the low TSS/COD ratio. A more typical value would be on the order of 0.40 mg COD / mg COD.

Influent Flocculated/Filtered COD/Total COD ratio: The overall average value of 0.47 mg COD / mg COD is significantly higher than typical for raw municipal wastewater. A more typical value would be 0.25 mg COD / mg COD.

Mixed liquor VSS/TSS ratio: The average value of 0.84 mg VSS / mg TSS is higher than the typically observed value of 0.75 mg VSS / mg TSS for sludge withdrawn from a system treating raw municipal wastewater (such as the SBR in this study). In fact, 0.84 mg VSS / mg TSS is a value typically observed for a system treating ***settled*** municipal wastewater. The higher than anticipated ratio is a consequence of the high-strength influent COD and relatively low influent solids concentration noted above.

Table 4-1 Influent Daily Results from SBR Intensive Monitoring Period

DATE	DAY	INFLUENT										
		TSS (mg/L)	VSS (mg/L)	COD tot. (mg/L)	COD gf filt. (mg/L)	COD ff (mg/L)	TP tot. (mg/L)	PO4-P (mg/L)	TKN tot. (mg/L)	TN tot. (mg/L)	NO3 (mg/L)	NH3 (mg/L)
Mon-Jul 29-13	48	188	160	801	558	439	5.51	2.39	40.2	40.7	0.5	23.1
Tue-Jul 30-13	49	430	385	1136	540	366	5.70	2.13	45.4	46.0	0.6	23.9
Wed-Jul 31-13	50	228	191	631	368	280	4.82	1.86	37.6	38.3	0.7	22.8
Thu-Aug 1-13	51	358	291	822	371	276	6.22	1.80	42.6	43.3	0.7	19.8
Fri-Aug 2-13	52	203	177	644	380	306	4.82	2.17	36.1	36.8	0.7	22.0
Sat-Aug 3-13	53			578	459	353	3.41	1.86	29.8	30.5	0.8	19.3
Sun-Aug 4-13	54			520	416	321	2.81	1.50	24.9	25.5	0.5	17.6
Mon-Aug 5-13	55	210	188	596	354	266	4.75	2.22	36.7	37.3	0.5	23.0
Tue-Aug 6-13	56	244	213	790	453	335	4.98	2.10	35.8	36.4	0.6	22.3
Wed-Aug 7-13	57	282	239	865	463	373	5.18	2.14	40.7	41.1	0.4	25.4
Thu-Aug 8-13	58	165	143	668	426	333	4.66	2.13	35.5	36.0	0.5	22.4
	AVG ALL	256	221	732	435	331	4.80	2.03	36.8	37.4	0.6	21.9

Table 4-2 SBR Unit Daily Results from SBR Intensive Monitoring Period

DATE	DAY	REACTOR TSS (mg/L)	VSS (mg/L)	COD tot. (mg/L)	TN tot. (mg/L)	OXYGEN UTILIZED (mg/d)
Mon-Jul 29-13	48	1645	1405	2197	151.9	4961
Tue-Jul 30-13	49	1838	1560	2434	143.2	5527
Wed-Jul 31-13	50	1707	1440	2333	147.5	4693
Thu-Aug 1-13	51	1848	1573	2304	139.0	4382
Fri-Aug 2-13	52	1758	1460	2207	143.7	4271
Sat-Aug 3-13	53	1598	1345	2026	127.7	4175
Sun-Aug 4-13	54	1545	1290	1951	133.9	3829
Mon-Aug 5-13	55	1636	1366	2036	132.3	3748
Tue-Aug 6-13	56	1648	1373	2126	136.4	3747
Wed-Aug 7-13	57	1763	1472	2275	140.9	4608
Thu-Aug 8-13	58	1705	1437	2120	145.5	4369
	AVG ALL	1699	1429	2183	140	4392

Table 4-3 Decant Daily Results from SBR Intensive Monitoring Period

DATE	DAY	DECANT COD tot. (mg/L)	COD gf (mg/L)	COD ff (mg/L)	TN gf (mg/L)	NH3 (mg/L)	NO2 (mg/L)	NO3 (mg/L)	NOx (mg/L)	TSS (mg/L)	VSS (mg/L)
Mon-Jul 29-13	48	152	36	19	20.5	0.823	0.055	18.3	18.3	107	92
Tue-Jul 30-13	49	154	36	19	16.9	0.054	0.020	13.7	13.7	126	103
Wed-Jul 31-13	50	134	33	20	19.5	0.066	0.034	17.6	17.6	105	84
Thu-Aug 1-13	51	132	39	16	16.7	0.081	0.069	15.2	15.2	112	85
Fri-Aug 2-13	52	108	29	16	20.6	0.115	0.043	19.9	19.9	95	74
Sat-Aug 3-13	53	110	43	29	16.8	0.057	0.079	14.8	14.8	77	62
Sun-Aug 4-13	54	105	39	25	14.1	0.079	0.152	11.8	12.0	66	57
Mon-Aug 5-13	55	122	33	26	21.3	0.057	0.121	19.2	19.3	98	76
Tue-Aug 6-13	56	125	37	27	18.4	0.014	0.020	17.0	17.0	99	78
Wed-Aug 7-13	57	116	54	33	18.1	0.043	0.070	16.6	16.7	88	73
Thu-Aug 8-13	58	115	52	24	17.2	0.036	0.026	16.2	16.2	88	73
	AVG ALL	125	39	23	18.2	0.129	0.062	16.4	16.44	96	78

Table 4-4 **Nitrogen Mass Balance on Intensive Testing Period Data**

DATE	DAY	NITROGEN INPUT (mgN/d)	NO3 out (mgN/d)	NO2 out (mgN/d)	NH3 out (mgN/d)	Nos+Nus out (mgN/d)	Eff. VSS (mgN/d)	WAS (mgN/d)	OUTPUT (mgN/d)
Mon-Jul 29-13	48	322	146	0.44	6.58	11	63	82	309
Tue-Jul 30-13	49	363	110	0.16	0.43	25	64	79	278
Wed-Jul 31-13	50	301	140	0.27	0.53	15	58	80	294
Thu-Aug 1-13	51	341	121	0.55	0.64	11	55	76	264
Fri-Aug 2-13	52	289	159	0.34	0.92	4	49	77	291
Sat-Aug 3-13	53	238	118	0.63	0.45	15	39	69	243
Sun-Aug 4-13	54	199	94	1.21	0.63	16	38	75	225
Mon-Aug 5-13	55	294	154	0.96	0.45	15	49	69	288
Tue-Aug 6-13	56	286	136	0.16	0.11	11	52	74	273
Wed-Aug 7-13	57	326	133	0.56	0.34	11	45	77	266
Thu-Aug 8-13	58	284	130	0.21	0.28	7	49	80	266
CUMULATIVE TOTAL		3242				Overall %	92		2998

Table 4-5 COD Mass Balance on Intensive Testing Period Data

DATE	DAY	COD INPUT (mg/d)	Eff. (mg/d)	WAS (mg/d)	OURt (mg/d)	OURn (mg/d)	OURc (mg/d)	OUTPUT (mg/d)
Mon-Jul 29-13	48	6405	1117	1373	4961	669	4293	6783
Tue-Jul 30-13	49	9088	1137	1521	5527	501	5025	7684
Wed-Jul 31-13	50	5051	985	1458	4693	643	4050	6493
Thu-Aug 1-13	51	6579	973	1440	4382	556	3826	6239
Fri-Aug 2-13	52	5155	799	1380	4271	729	3542	5720
Sat-Aug 3-13	53	4620	812	1266	4175	541	3633	5712
Sun-Aug 4-13	54	4157	771	1220	3829	436	3394	5384
Mon-Aug 5-13	55	4764	896	1273	3748	705	3043	5211
Tue-Aug 6-13	56	6323	924	1329	3747	622	3125	5378
Wed-Aug 7-13	57	6920	853	1422	4608	609	4000	6274
Thu-Aug 8-13	58	5344	847	1325	4369	593	3776	5948
CUMULATIVE TOTAL		64405		Overall %	104			66826

Table 4-6 Relevant Influent and Mixed Liquor Ratios

DATE	DAY	INFLUENT TSS / COD (mg/mg)	ISS / TSS (mg/mg)	ISS / COD (mg/mg)	VSS / TSS (mg/mg)	TKN / COD (mg/mg)	TP / COD (mg/mg)	COD gf / COD tot (mg/mg)	COD ff / COD tot (mg/mg)	MIXED LIQUOR ISS (mg/L)	VSS/ TSS
Mon-Jul 29-13	48	0.23	0.15	0.03	0.85	0.05	0.007	0.70	0.55	240	0.85
Tue-Jul 30-13	49	0.38	0.10	0.04	0.90	0.04	0.005	0.48	0.32	278	0.85
Wed-Jul 31-13	50	0.36	0.16	0.06	0.84	0.06	0.008	0.58	0.44	267	0.84
Thu-Aug 1-13	51	0.43	0.19	0.08	0.81	0.05	0.008	0.45	0.34	275	0.85
Fri-Aug 2-13	52	0.32	0.13	0.04	0.87	0.06	0.007	0.59	0.47	298	0.83
Sat-Aug 3-13	53					0.05	0.006	0.79	0.61	253	0.84
Sun-Aug 4-13	54					0.05	0.005	0.80	0.62	255	0.83
Mon-Aug 5-13	55	0.35	0.11	0.04	0.89	0.06	0.008	0.59	0.45	271	0.83
Tue-Aug 6-13	56	0.31	0.12	0.04	0.88	0.05	0.006	0.57	0.42	275	0.83
Wed-Aug 7-13	57	0.33	0.15	0.05	0.85	0.05	0.006	0.53	0.43	292	0.83
Thu-Aug 8-13	58	0.25	0.13	0.03	0.87	0.05	0.007	0.64	0.50	268	0.84
	AVG ALL	0.33	0.14	0.05	0.86	0.05	0.007	0.61	0.47	270	0.84

4.5 MODEL PARAMETERS FROM DIRECT MEASUREMENT

Table 4-7 lists various influent wastewater fractions and stoichiometric values required as input for process simulation. Again, in a few instances values are missing either because data were not available, or the data used to calculate the values were suspect.

Influent Inorganic Suspended Solids Concentration (ISS): The overall average ISS concentration was 35 mg/L. In calculating this average, the ISS concentrations on August 3rd and 4th were excluded because they were very low, i.e. 13 mg/L and 8 mg/L, respectively.

Influent soluble readily biodegradable COD fraction (f_{BS}): The overall average f_{BS} value estimated by dividing the difference of the influent and effluent ffCOD by the influent TCOD (as per equation 2.2) was 0.41 mg COD / mg COD. This value is much higher than the typical value of 0.16 mg COD / mg COD for raw municipal wastewater. In calculating this average, the f_{BS} values on August 3rd and 4th, *i.e.* 0.56 and 0.57, respectively, were excluded because they were much higher than the other values in the dataset. It should be noted that these were the days that exhibited unusually low COD:TSS ratios and unusually high ratios for glass-fibre and floc/filtered COD to TCOD. This physical/chemical based f_{BS} estimate was further refined by simulating the system, as will be discussed in section 4.6.

Influent soluble unbiodegradable COD fraction (f_{US}): The overall average value of 0.03 mg COD / mg COD is slightly lower than the typical value of 0.05 mg COD / mg COD for raw municipal wastewater.

Influent Ammonia/TKN fraction (f_{NA}): The overall average value of 0.60 mg N / mg N is slightly lower than the typical value of 0.66 mg N / mg N for raw municipal wastewater.

Influent soluble unbiodegradable TKN fraction (f_{NUS}): The overall average value of 0.03 mg N / mg N is slightly higher than the typical value of 0.02 mg N / mg N for raw municipal wastewater.

Mixed liquor COD/VSS ratio ($f_{CV,ML}$): The average value of 1.50 mg COD / mg VSS is slightly higher than the typical value of 1.48 mg COD / mg VSS for sludge drawn from a system treating raw municipal wastewater.

Nitrogen content of mixed liquor solids (f_N): The average value of 0.09 mg N / mg VSS is close to the typical value of 0.10 mg N / mg VSS for sludge drawn from a system treating raw municipal wastewater.

Table 4-7 Influent Wastewater Characteristics and Other Stoichiometric Parameters

DATE	DAY	INFLUENT ISS (mg/L)	INFLUENT TKN* (TN-NO3) (mg/L)	INFLUENT Fbs (mg/L)	INFLUENT Fus (mg/L)	INFLUENT Fcv (mgCOD/mgVSS)	INFLUENT Fnus (mgN/mgN)	INFLUENT Fpo4 (mgP/mgP)	INFLUENT Fna (mgN/mgN)	MIXED LIQUOR Fcv (mgCOD/mgVSS)	MIXED LIQUOR Fn (mgN/mgVSS)
Mon-Jul 29-13	48	28	40.2	0.52	0.02	1.52	0.02	0.43	0.57	1.54	0.09
Tue-Jul 30-13	49	45	45.4	0.31	0.02	1.55	0.06	0.37	0.53	1.54	0.08
Wed-Jul 31-13	50	37	37.6	0.41	0.03	1.38	0.04	0.39	0.61	1.60	0.09
Thu-Aug 1-13	51	67	42.6	0.32	0.02	1.55	0.02	0.29	0.46	1.44	0.08
Fri-Aug 2-13	52	26	36.1	0.45	0.02	1.49	0.00	0.45	0.61	1.49	0.08
Sat-Aug 3-13	53		29.8		0.05		0.05	0.54	0.65	1.47	0.08
Sun-Aug 4-13	54		24.9		0.05		0.06	0.53	0.70	1.48	0.09
Mon-Aug 5-13	55	22	36.7	0.40	0.04	1.28	0.04	0.47	0.62	1.47	0.08
Tue-Aug 6-13	56	30	35.8	0.39	0.03	1.58	0.02	0.42	0.62	1.52	0.09
Wed-Aug 7-13	57	43	40.7	0.39	0.04	1.68	0.02	0.41	0.62	1.51	0.08
Thu-Aug 8-13	58	22	35.5	0.46	0.04	1.69	0.01	0.46	0.63	1.44	0.09
	AVG ALL	35	36.8	0.41	0.03	1.53	0.03	0.43	0.60	1.50	0.09

4.6 MODEL PARAMETERS ESTIMATED FROM SIMULATION

Certain model parameters cannot be determined readily by direct measurement. For this study, these were estimated iteratively using simulation. The simulation approach also provides a basis for confirming estimates of certain parameters such as the soluble readily biodegradable influent COD fraction (f_{BS}) and the fraction of the influent TKN which is soluble unbiodegradable (f_{NUS}).

The simulation study of the SBR was conducted to model the system response over the intensive monitoring period. Operating conditions such as the influent volume and the various periods in the SBR cycle time were set up in the simulator. The influent COD, TKN and ISS concentrations for each day were specified in the influent element, together with the fractional characteristics determined from the direct measurements.

The initial simulation of the system revealed that the biomass was phosphorous limited. The phosphate level in the reactor dropped to zero repeatedly from June 11th until August 9th, 2013. This was a consequence of the lower-than-typical TP/COD influent ratio (0.007 mg P / mg COD). However, the measured responses in the reactor and decant stream during the intensive testing period did not indicate that the SBR system was in fact phosphorous-limited. The daily OUR profiles showed expected levels of biomass growth. In order to remove this limitation, the phosphorous content of the heterotrophs (the dominant population of microorganisms) was reduced until the system was no longer phosphorous-limited. The phosphorous content of the heterotrophs was reduced from the BioWin default value of 0.022 to 0.007 mg P / mg COD.

A number of simulation runs were performed, iteratively varying the values of the parameters to be estimated (*e.g.* f_{UP}, μ_{AOB}, μ_{NOB}). The objective was to obtain a reasonable agreement between simulated response and observed data over the intensive period.

4.6.1 SOLUBLE READILY BIODEGRADABLE COD (f_{BS})

The simulation of the two nitrification profile days revealed that the initial f_{BS} estimate of 0.41 mg COD / mg COD was too high. Three main responses were used to determine this:

1. Simulating the system with an f_{BS} value of 0.41 mg COD / mg COD predicted an initial rapid ammonia removal rate (for the synthesis of new cells) that was not observed on either profile day. The simulated ammonia removal rate matched the observed rate more closely when a lower f_{BS} value was used for simulation (refer to Figures 4-11 and 4-13).
2. The predicted duration of the OUR peak immediately after the reactor was fed (associated with the utilization of RBCOD) was longer than observed when the initial high estimate of f_{BS} was used. The duration of the initial high OUR period was better matched by simulating with a lower f_{BS} value (refer to Figures 4-12 and 4-14).
3. The measured OUR decreased gradually following the initial OUR peak (refer to Figures A-4 through A-11). This gradual decline in the OUR curve indicated that

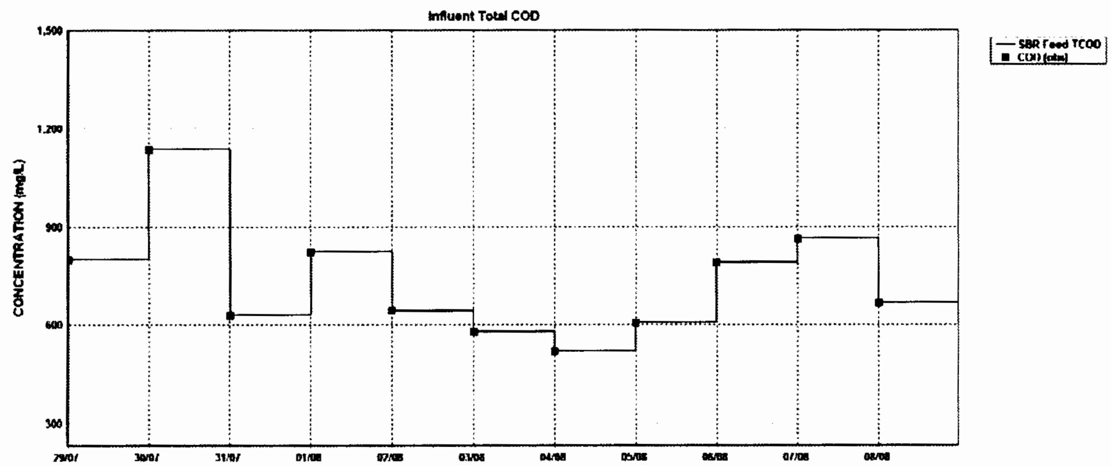
the influent contained biodegradable compounds that manifested as soluble in the ffCOD tests, but biologically were not truly "readily biodegradable".

A number of simulation runs were performed, iteratively varying the f_{BS} value. It was found that the system could be accurately simulated with an f_{BS} value of 0.21 mg COD / mg COD. The remaining soluble biodegradable COD (*i.e.* the 0.41 mg COD / mg COD estimated *via* the ffCOD method less the 0.21 mg COD / mg COD estimated through simulating the observed biological response; 0.20 mg COD / mg COD) fraction not assigned as ***readily*** biodegradable COD was assigned as colloidal COD for modelling purposes. The daily OUR plots will be presented in Appendix A.

4.6.2 UNBIODEGRADABLE PARTICULATE COD (f_{UP})

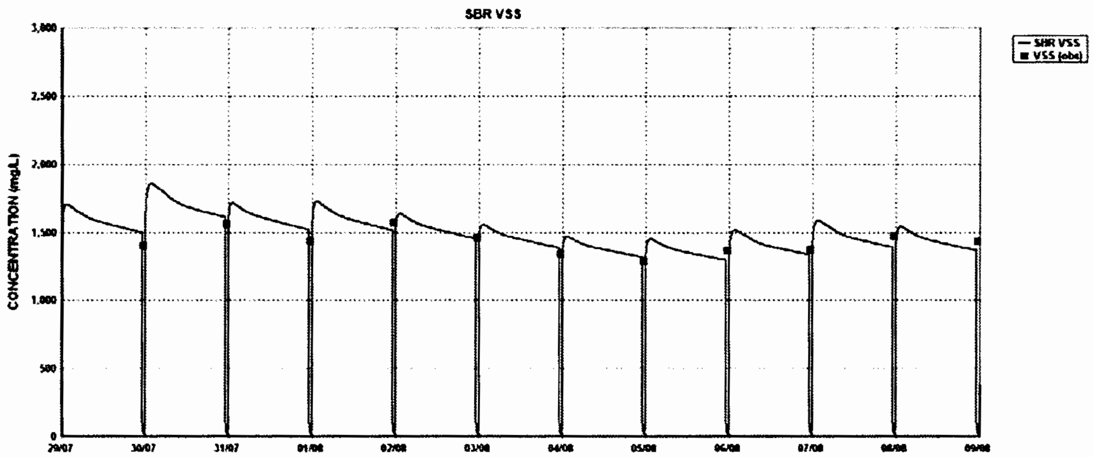
In the case of f_{UP}, the primary parameter response to match through simulation is the SBR VSS concentration. Figure 4-1 shows the influent COD concentration variation over the 11 days of intensive monitoring. This is shown as a continuous line, with constant sections for each day corresponding to the measured influent COD of the influent feed.

Figure 4-1 Influent Feedstock COD Concentration to the Bench-Scale SBR Unit



A number of simulation runs were performed, iteratively varying the value of the unbiodegradable particulate COD fraction to be estimated, f_{UP}. The objective was to obtain a reasonable fit of simulated to observed MLVSS concentration. An f_{UP} value of 0.10 mg COD / mg COD provided good correspondence between the simulated and observed VSS concentration in the system. This value is lower than the typical value of 0.13 mg COD / mg COD for a raw municipal wastewater and is in fact close to the typical value of 0.08 mg COD / mg COD for a primary settled wastewater. Figure 4-2 shows a plot of the simulation results over the intensive period. It should be noted that the experimental data points correspond to the VSS concentration in the waste sludge drawn from the reactor at the end of the daily cycle just prior to commencing settling and decant. [Note that the simulator predicts a decrease in solids concentration over the course of each day. This is due to normal biological activity, and is expected. At the end of each day, the simulator shows the solids concentration rapidly plunging to zero and then increasing over a very short time period. This solids concentration fluctuation arises when the simulator enters the decant and fill phases.]

Figure 4-2 Simulated (solid line) and Observed (points) MLVSS in the SBR



Figures 4-3 and 4-4 show the respective plots for TSS and ISS concentration in the SBR. As can be seen in these figures, the predicted TSS and ISS values match the corresponding measured values very well. The predicted ISS concentration in the SBR is a function of the influent ISS concentration and SRT in the SBR. Because the influent ISS concentration was not measured during the start-up period, these values were initially estimated by multiplying the average influent ISS/TSS ratio measured for the intensive period (0.14 mg SS / mg SS) by each measured influent TSS concentration. On days when the influent TSS concentration was not measured, the data were interpolated. Using this dataset of influent ISS concentrations, the SBR was then simulated from June 11th until August 9th, 2013. It was found that the predicted ISS concentrations in the SBR were higher than the measured concentrations during the intensive period. The dataset of influent ISS concentration during the start-up period was then reduced by a factor and the SBR system was simulated again. Ultimately, the influent ISS during the start-up was used as a calibration parameter. However, due to the fact that it was not measured during start-up and there also were gaps in the measured TSS, the intensive monitoring period influent ISS content should be used for modelling / design purposes.

Figure 4-3 Simulated (solid line) and Observed (points) TSS in the SBR

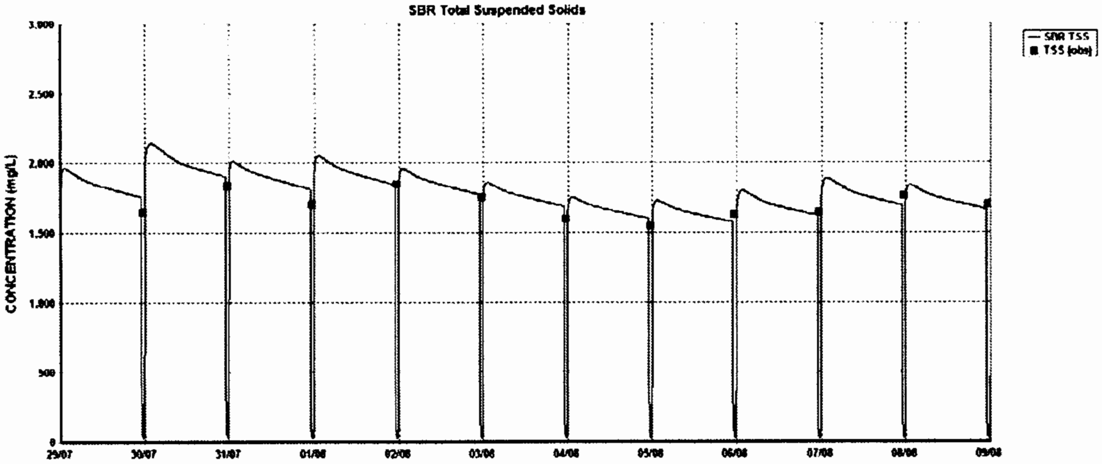
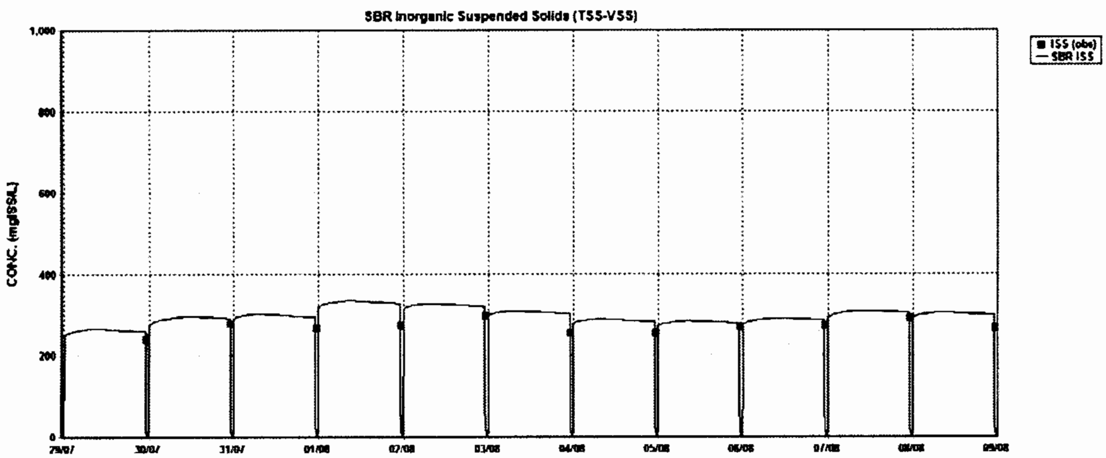


Figure 4-4 Simulated (solid line) and Observed (points) ISS in the SBR



Other simulated responses serve as secondary checks on the f_{UP} estimate. The simulator requires COD, TKN, TP, ISS, *etc.* as inputs. It does not explicitly accept measured influent TSS and VSS data as inputs, rather, the simulator calculates influent TSS and VSS as a result of the input "total" measurements (*e.g.* COD) and the wastewater characteristic fractions. The unbiodegradable particulate COD fraction has a significant impact on the simulator-predicted influent VSS; therefore a check on the f_{UP} estimate is how well the predicted influent VSS matches the observed values. Figure 4-5 shows that generally the overall trends are matched, throughout both the acclimatization and intensive periods. The predicted values did not match the extremely low and high measured solids concentrations. This may indicate errors in these extreme measured solids concentrations, or different wastewater fractionation on days with very high or low concentrations (as was observed in the intensive period).

The unbiodegradable particulate COD contributes significantly to the reactor total COD at the 16-day target sludge age in the SBR. The simulator requires as an input a COD/VSS ratio for both unbiodegradable (*i.e.* $f_{CV,XI}$) and biodegradable particulate COD (*i.e.* $f_{CV,XS}$); the model default is 1.6 for each. Figure 4-6 shows the simulated and observed responses for the SBR total COD; this fit was obtained using an $f_{CV,XI}$ value of 1.6 mg COD / mg VSS and an $f_{CV,XS}$ value of 1.4 mg COD / mg VSS. As with the VSS response, it should be noted that the experimental data points correspond to the COD concentration of the waste sludge drawn from the reactor at the end of the daily cycle just prior to commencing settling and decant. Figure 4-7 shows the good match between predicted and observed SBR mixed liquor COD:VSS ratios which, along with the MLVSS and influent solids predictions, is further validation of the f_{UP} and f_{CV} estimates.

Figure 4-5 Simulated (lines) and Observed (points) Influent Feedstock TSS and VSS.

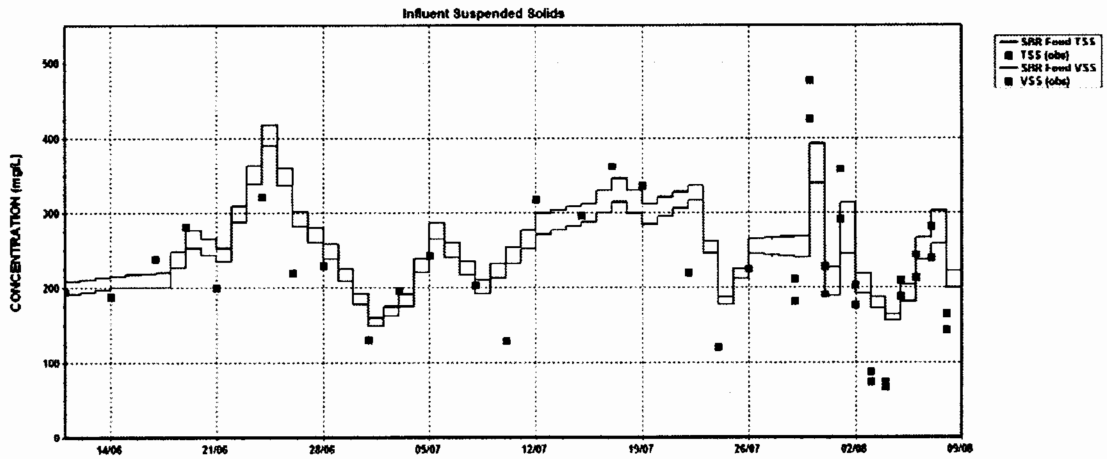


Figure 4-6 Simulated (solid line) and Observed (points) SBR Total COD.

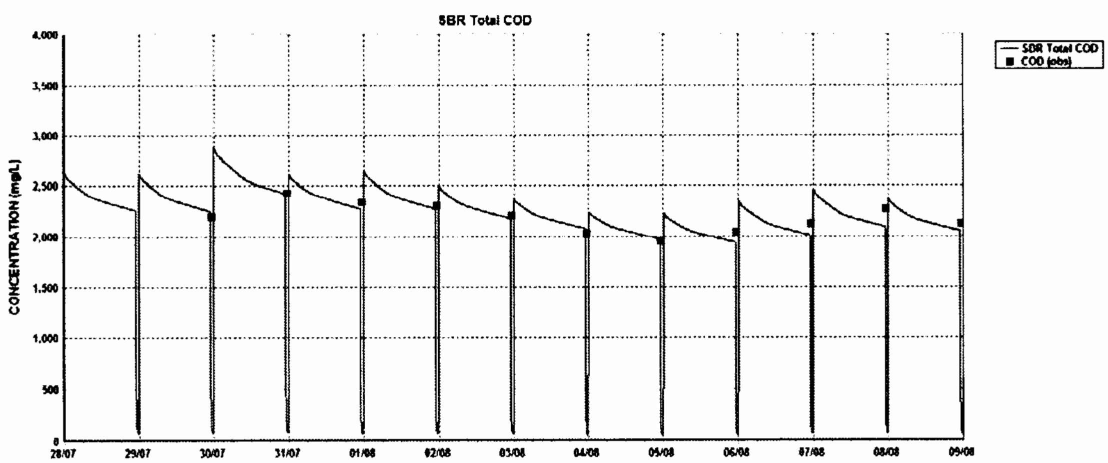
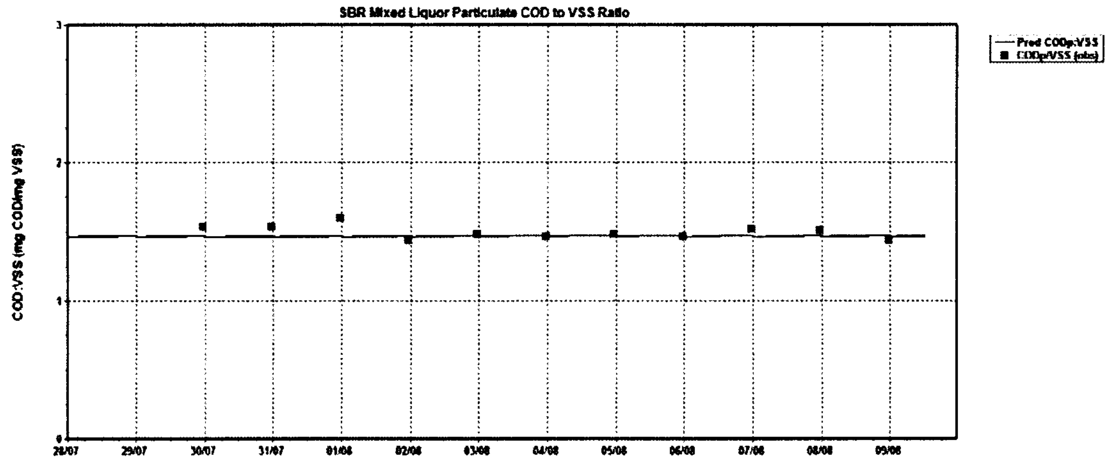


Figure 4-7 Simulated (solid line) and Observed (points) SBR Mixed Liquor COD:VSS.



4.6.3 NITRIFICATION RATES (μ_{AOB}, μ_{NOB})

Nitrification performance essentially is quantified by the maximum specific growth rates of the nitrifiers in the system. Experience has shown that the nitrification rates may vary substantially from plant to plant, often due to industrial discharges causing inhibition of the population of nitrifying microorganisms. The implication of low nitrifier growth rates is that the system must be operated at a long SRT to avoid washout of nitrifiers. This in turn translates into an increased sludge mass in the system, resulting in either increased reactor tankage and clarifier area for new plant designs or reduced treatment capacity for existing plants. Pilot testing, such as the type performed in this study, should be conducted to determine whether the raw influent stream inhibits nitrifiers. Otherwise, design and/or capacity rating necessarily should be based on conservative (low) estimates. This in turn can have a substantial capital cost and planning implications.

Similar to f_{UP}, the maximum specific growth rates of the nitrifiers (μ_{AOB}, μ_{NOB}) also are determined in an iterative fashion. However, in this case the data to be matched are the responses of ammonia, nitrite and nitrate over the first several hours for the days of SBR operation where profile data were collected (July 31st and August 2nd).

Figure 4-8 shows the variation of the influent TKN concentration over the intensive period and ammonia concentration over the entire study period. The influent ammonia concentration varied between about 20 mg N / L and 30 mg N / L, except for a few measurements which fell outside this range and were considered outliers. The consistency of the measured ammonia concentration throughout the start-up phase suggests that TKN levels would have been similar to the intensive period levels had they been monitored throughout start-up. As with the COD plot, the simulated TKN concentration is shown as a continuous line, with constant sections for each day corresponding to the measured influent TKN of the influent feed. The predicted ammonia (a consequence of the TKN concentrations and f_{NA} fraction input to the simulator) is also shown as a continuous line; daily measurements of ammonia are shown as points.

Figure 4-8 Influent Feedstock TKN and Ammonia Concentration to the Bench-Scale SBR Unit.

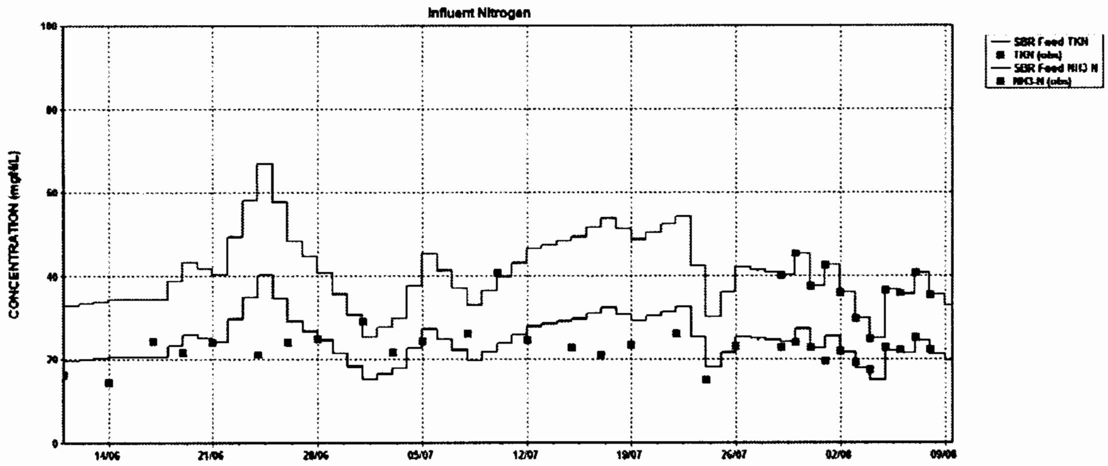


Figure 4-9 shows the simulated and observed decant (effluent) nitrate and nitrite concentrations. The variation in effluent nitrate is tracked well. Note that the data correspond to the concentration in the decant volume drawn from the reactor at the end of the settle period so the experimental data points should lie at the top of each simulated "spike". This good fit is a validation of the estimated f_{NA} and f_{NUS} parameters. An additional validation of the f_{NUS} parameter is the accurate simulation of the soluble nitrogen concentration in the decant volume, as will be shown in Figure 4-18.

Figure 4-9 Simulated (solid line) and Observed (points) Nitrite and Nitrate in the SBR.

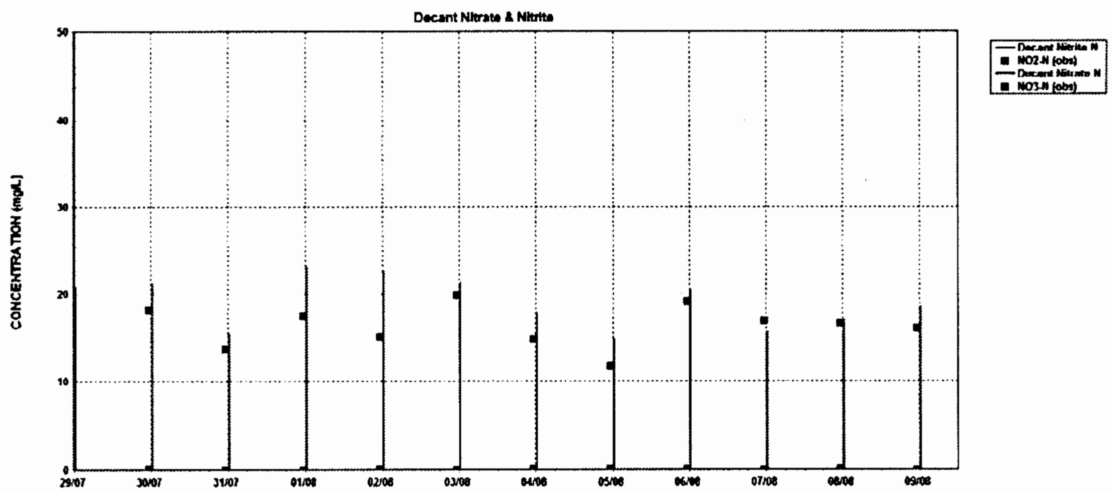
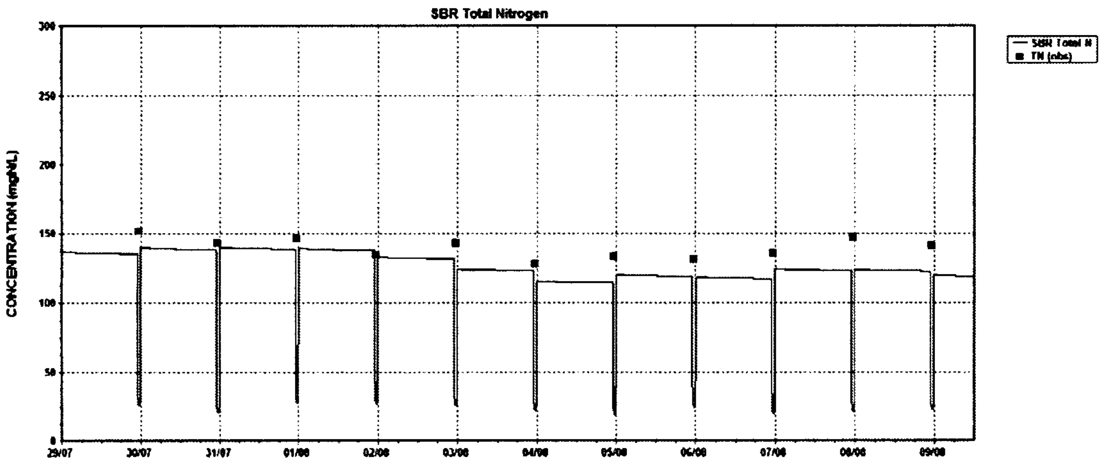


Figure 4-10 shows the simulated and observed Total Nitrogen content of the reactor solids. There is not a great deal of variability in the predicted nitrogen content, indicating that the system was at a reasonably steady state. The predicted TN concentrations match the observed data reasonably well, which is anticipated based on the good mass balance achieved, i.e. a 92% closure on nitrogen. These factors indicate that the system is suitable for estimating the nitrification rates via simulation.

Figure 4-10 Simulated (solid line) and Observed (points) Total Nitrogen in the SBR.



The nitrifier maximum specific growth rates (μ_{AOB}, μ_{NOB}) were estimated by iteratively adjusting their values to obtain a fit to the ammonia, nitrite, and nitrate profiles on the two days where profile data were gathered (July 31st and August 2nd). The nitrification behaviour in the system could be accurately simulated for both profile days with a μ_{AOB} value of 0.62 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d^{-1}], and a μ_{NOB} value of 0.70 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.06 and an aerobic decay rate of 0.17 d^{-1}]. Nitrite and nitrate data for the first and second profile days are shown for the first 12 hours of the SBR cycle in Figures 4-11 and 4-13, together with ammonia concentration. A good fit is generally obtained to all of the various profile responses. For the rest of the simulation days during the start-up and intensive periods, the μ_{AOB} and μ_{NOB} values were set at 0.62 d^{-1} and 0.7 d^{-1}, respectively.

Because a number of factors impact the ammonia removal rate (*e.g.* ammonia also is consumed in the system to meet cellular synthesis requirements of non-nitrifying organisms in the activated sludge mass; ammonia also is produced through decay of these organisms; ammonia is produced *via* hydrolysis/ammonification of influent organic nitrogen), it is important to focus on the slopes of the NO_3 and NO_2 responses when estimating values for μ_{AOB} and μ_{NOB}. Although there is a slight difference in the intial NOx concentrations evident in Figures 4-11 and 4-13 (which could be improved by encouraging slightly more denitrification during the settle/decant phase in the modelled system), it is important to note that the ***slopes*** of the predicted and observed NOx are very close. Using the μ_{AOB} and μ_{NOB} values discussed above results in very good agreement between the slopes for the initial linear period of the predicted and observed NOx responses. On the first profile day, the predicted and observed slopes are within 0.5%; on the second profile day, the predicted and observed slopes are within 2.9%.

The OUR responses in the SBR on July 31st and August 2nd are presented in Figures 4-12 and 4-14. Oxygen utilization rate (OUR) response is closely linked to nitrification behaviour. A further check on the selection of the nitrification rate parameters is provided by examining the observed response of OUR over the cycle. Figure 4-12 shows the results for July 31st. The initial drop in the OUR curve within the first hour of the test coincides with the depletion of RBCOD in the reactor. The transition between the initial high OUR associated with RBCOD and the "plateau" associated predominantly with nitrification was less well-defined compared to typical OUR responses. This suggests that the influent contained soluble biodegradable compounds with a range of biodegradation rates, *i.e.* not truly readily biodegradable. Following this initial OUR drop, the OUR response "turns down" at around 6 hours into the feed cycle. This coincides with the completion of nitrification (note that the horizontal axis of the OUR profile covers a longer time frame [*i.e.* the full REACT cycle] than the nitrogen species profile). The fact that the "turn down time" of the OUR profile agrees with the ammonia depletion time corroborates the nitrification rate estimates. Until the ammonia is depleted, nitrification will continue at the maximum rate and the nitrogenous OUR will be constant since the nitrifier organism mass in the SBR is constant. In Figure 4-12, the nitrogenous OUR plateau is not clearly visible because soluble compounds with slower biodegradation rates continued to be oxidized after the initial mass of ***readily*** biodegradable COD was depleted.

Although the BioWin 4.0 default μ_{NOB} rate of 0.7 d^{-1} was successfully used to fit the nitrification behaviour in the SBR, the fitted μ_{AOB} rate was much lower than the BioWin 4.0 default value of 0.9 d^{-1}. EnviroSim has conducted nitrification rate tests at numerous North American WWTPs over several years and has generated datasets of μ_{NOB} and μ_{AOB} values. The default μ_{NOB} and μ_{AOB} values in BioWin represent the average values of these large datasets. The low μ_{AOB} value in the current study indicates that the ammonia oxidizing biomass was inhibited during the intensive monitoring period. However, the nitrite oxidizing biomass did not appear to be inhibited. The consistently low nitrite levels (*i.e.* less than 1 mg N / L) throughout both profile days demonstrated that the maximum specific growth rate of the AOBs was lower than that of the NOBs. This was distinctly different from other similar studies in the past, during which the nitrite concentration peaked at levels around 5 mg N / L or higher over the course of the profile day (*e.g.* Figure 4-15, Jones *et al.* [2012]).

EnviroSim has previously measured low values for μ_{AOB}. For example, the nitrification behaviour of a laboratory-scale SBR system operated in March 2008 with wastewater from the Kitchener WWTP in Ontario, Canada, was accurately simulated with a μ_{AOB} value of 0.55 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d^{-1}] (Bye *et al.*, 2010). However, follow-up testing indicated that this inhibition was transient (Bye *et al.*, 2012). The follow-up testing outlined in Bye *et al.* (2012) consisted of extending the SBR protocol applied in this study to include daily monitoring of OUR throughout the start-up phase as well as the intensive monitoring phase. This allowed for the identification of days with significantly different OUR profiles that were indications of transient nitrifier inhibition (*e.g.* see Figure A-3).

This prior experience was the motivation for daily monitoring of OUR during the Fritz Island WWTP study. The following two points are worth noting with regard to the apparent nitrification inhibition observed for this study:

1. Although the estimated μ_{AOB} value is indicative of inhibited nitrification rates, the data suggest that this is not a case of transitory inhibition. That is, when examining the OUR profiles in Figures A-4 through A-11, there are no OUR profiles that stand out clearly as in the example shown in Figure A-3.
2. From examining Figure A-10 (which contains the OUR profiles for both nitrification rate estimation days [July 29th and August 2nd]), the two days for which nitrification rates were estimated do not stand out as having significantly lower nitrogenous OURs than other days.

Figure 4-11 Simulated (solid line) and Observed (points) Nitrite, Nitrate and Ammonia in the SBR (July 31st, 2013).

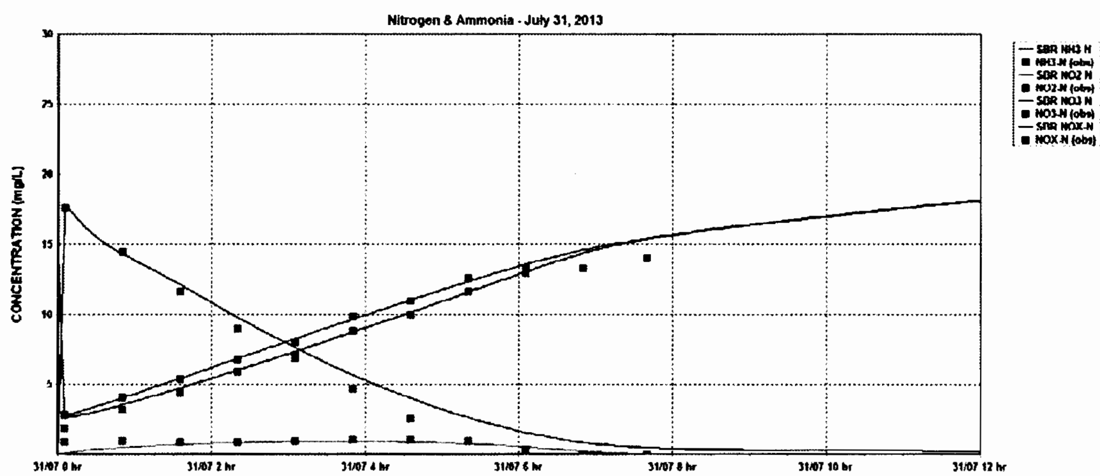


Figure 4-12 Observed OUR Response in the SBR (July 31st, 2013).

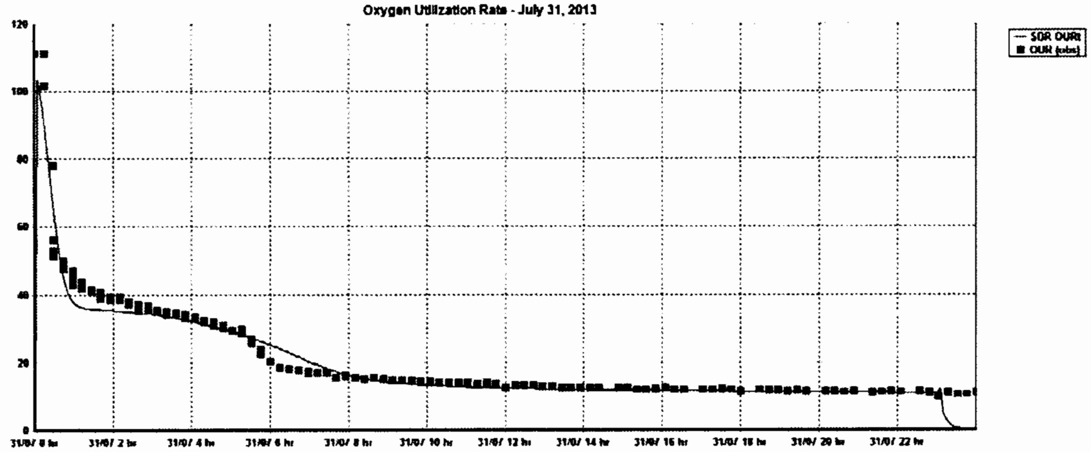


Figure 4-13 Simulated (solid line) and Observed (points) Nitrite, Nitrate and Ammonia in the SBR (August 2nd, 2013).

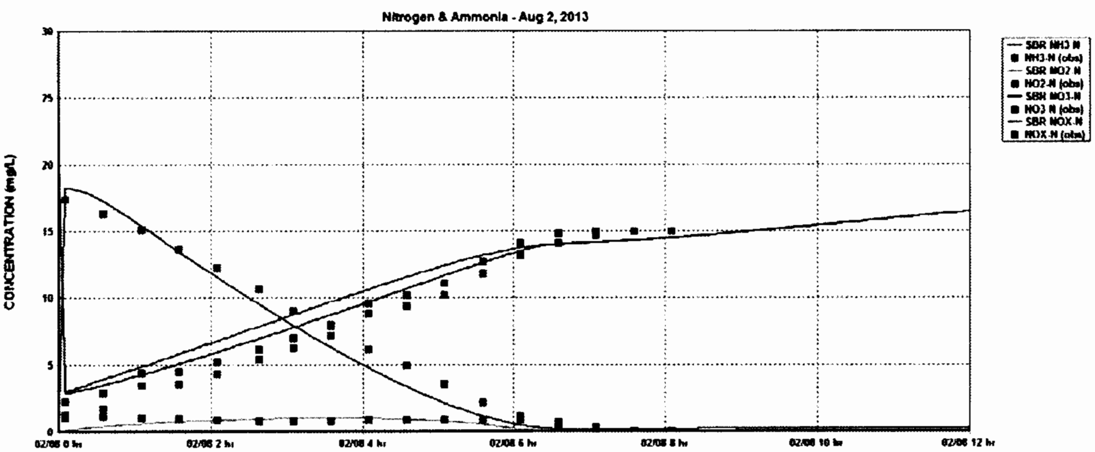


Figure 4-14 Observed OUR Response in the SBR (August 2nd, 2013).

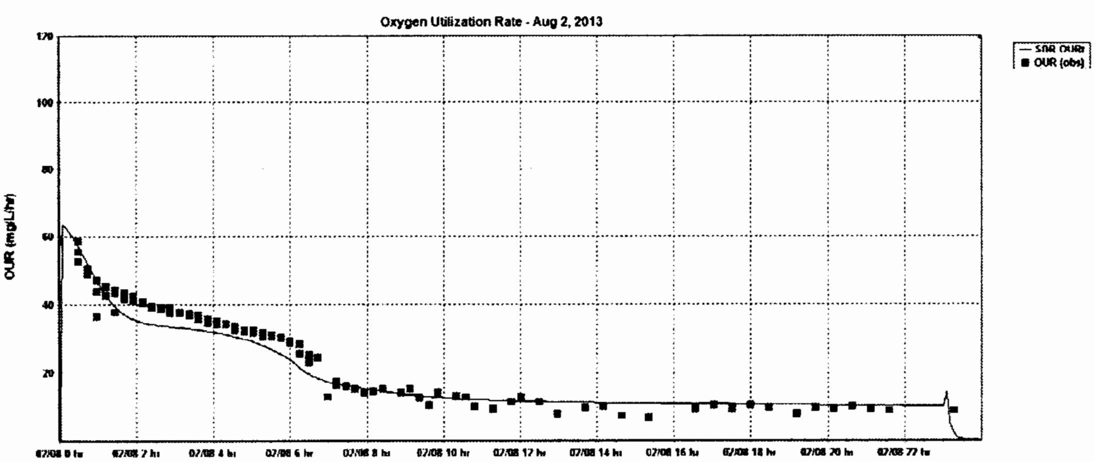
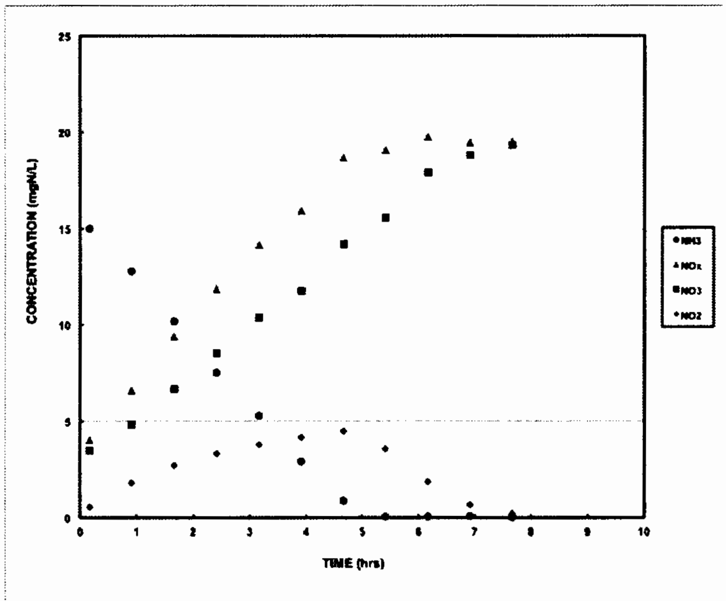


Figure 4-15 Nitrite peak typically observed in similar studies with no nitrification inhibition.



The nitrifier decay rates used to estimate nitrifier growth rates were not measured for this study since they have less of an impact on plant sizing. However, the assumed AOB and NOB decay rates of 0.17 d^{-1} are based on significant research (WERF, 2003). Other research [*e.g.* (Lee and Oleszkiewicz, 2002), (Dold *et al.*, 2005)] has reported similar values. Therefore it is recommended that the nitrification kinetic parameter sets listed in Table 4-8 and Table 4-9 be used for future model-based analysis activities.

Table 4-8 Summary of Ammonia Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{AOB,20}$ Ammonia oxidizing bacteria maximum specific growth rate	0.62	0.90	d^{-1}
$b_{AOB,20}$ Ammonia oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,AOB,NH4,20}$ Ammonia oxidizing bacteria substrate half-saturation constant (BioWin default, based on WERF, 2003)	0.70	0.70	mg N / L
$\Theta\mu_{AOB}$ Ammonia oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default, based on WERF, 2003)	1.072	1.072	
$\Theta\ b_{AOB}$ Ammonia oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

Table 4-9 Summary of Nitrite Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{NOB,20}$ Nitrite oxidizing bacteria maximum specific growth rate	0.70	0.70	d^{-1}
$b_{NOB,20}$ Nitrite oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,NOB,NO2,20}$ Nitrite oxidizing bacteria substrate half-saturation constant (BioWin default)	0.1	0.1	mg N / L
$\Theta\mu_{NOB}$ Nitrite oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default)	1.06	1.06	
$\Theta\ b_{NOB}$ Nitrite oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

4.7 ADDITIONAL SIMULATION PLOTS

Figures 4-16 to 4-20 show additional plots from the simulation run for a number of responses. Generally there is good agreement between simulated and observed responses, indicating that the model parameters selected for the SBR simulation are valid.

- **Influent TP and soluble phosphate:** The measured influent TP concentrations are input directly to the simulator and the average measured f_{PO4} fraction during the intensive period (0.43) is used to calculate the predicted soluble phosphate. As can be seen in Figure 4-16, the soluble phosphate concentrations are accurately simulated.
- **SBR Decant soluble COD:** When the average f_{US} value measured during the intensive period (0.03) was applied in the simulation, the predicted decant soluble COD concentrations were found to be generally lower than the measured values. This suggests that the influent unbiodegradable soluble COD (f_{US}) was higher than 0.03. The f_{US} value was then increased to 0.05 and the system was simulated again. This improved the match between the simulated and measured decant soluble COD concentrations and this is shown in Figure 4-17.
- **SBR Decant TSS:** As shown in Figure 4-18, the measured TSS concentration in the SBR decant was relatively high, indicating poor settling in the SBR. As previously mentioned, this was a consequence of operating the bench-scale SBR with very intense mixing to capture the high OURs associated with the strong feed. The clarification switching function settling parameter in the BioWin model was adjusted in order to match the measured solids concentrations in the decant during the intensive period while ensuring that the predicted reactor solids concentration remained accurate.
- **SBR Decant soluble nitrogen.** The fit of the simulated decant soluble nitrogen concentrations to the measured values provides verification of the unbiodegradable soluble nitrogen estimate (f_{NUS}). As previously mentioned, an

f_{NUS} value of 0.03 mg N / mg N was used throughout the simulation. Figure 4-19 shows the good agreement obtained between simulated and observed decant filtered nitrogen.

- **OUR response.** The good fit to the general profile of the measured daily OUR profiles is a validation of the estimated nitrification rate and influent f_{BS} value. In order to better simulate the very high OUR spikes that occurred immediately after the SBR was fed, the maximum specific growth rate of the ordinary heterotrophic organisms was increased from the BioWin default value of 3.2 d^{-1} to 4.8 d^{-1}.

Figure 4-16 Simulated (continuous) and Observed (points) Influent Phosphorus.

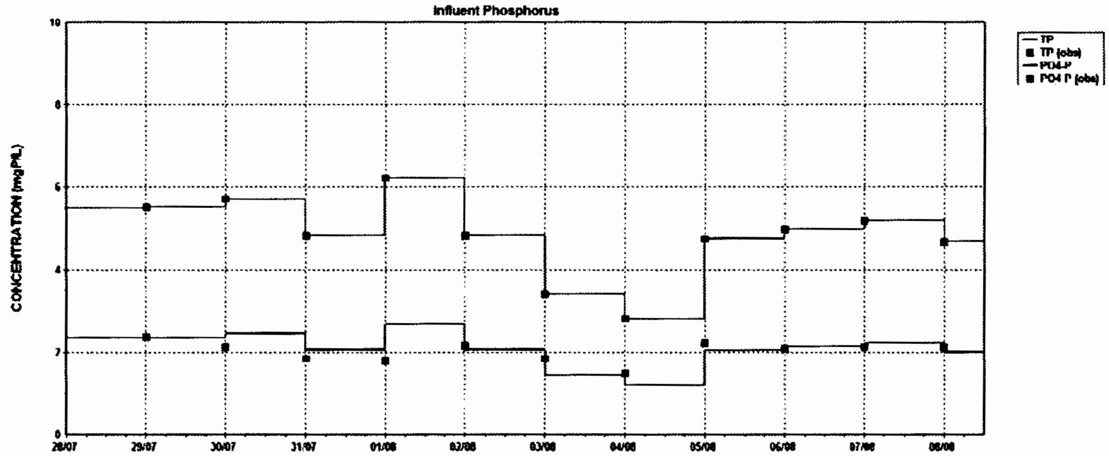


Figure 4-17 Simulated (spikes) and Observed (points) Total and Soluble COD in the SBR Decant.

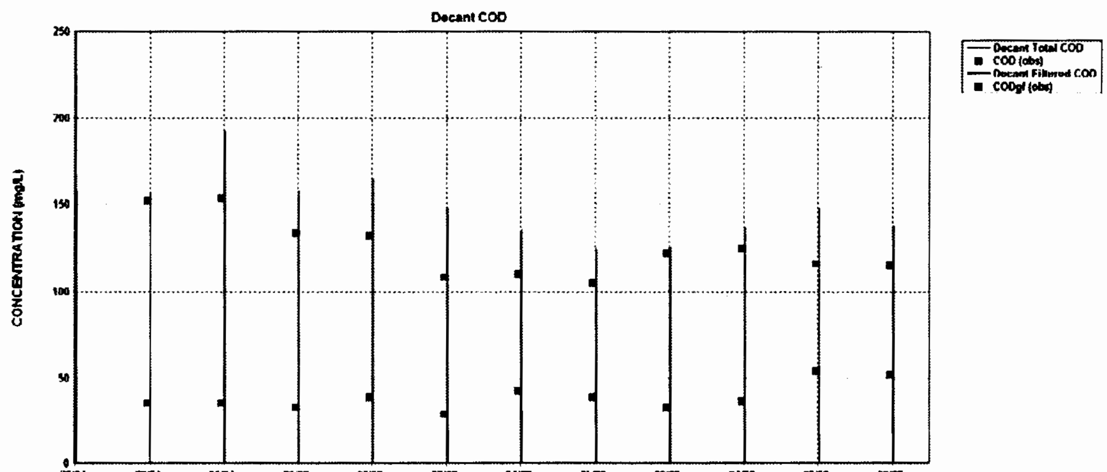


Figure 4-18 Simulated (spikes) and Observed (points) TSS in the SBR Decant.

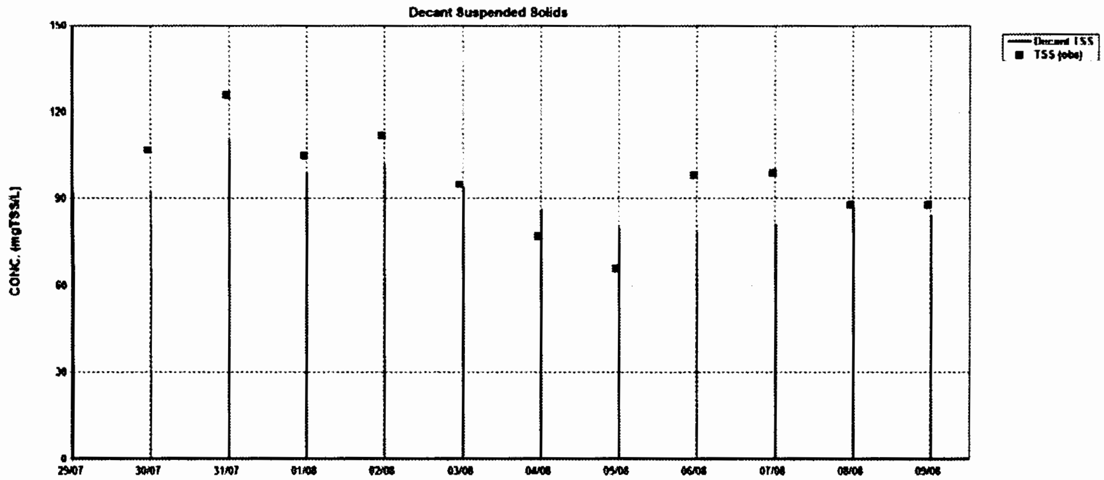


Figure 4-19 Simulated (spikes) and Observed (points) Soluble Nitrogen in the SBR Decant.

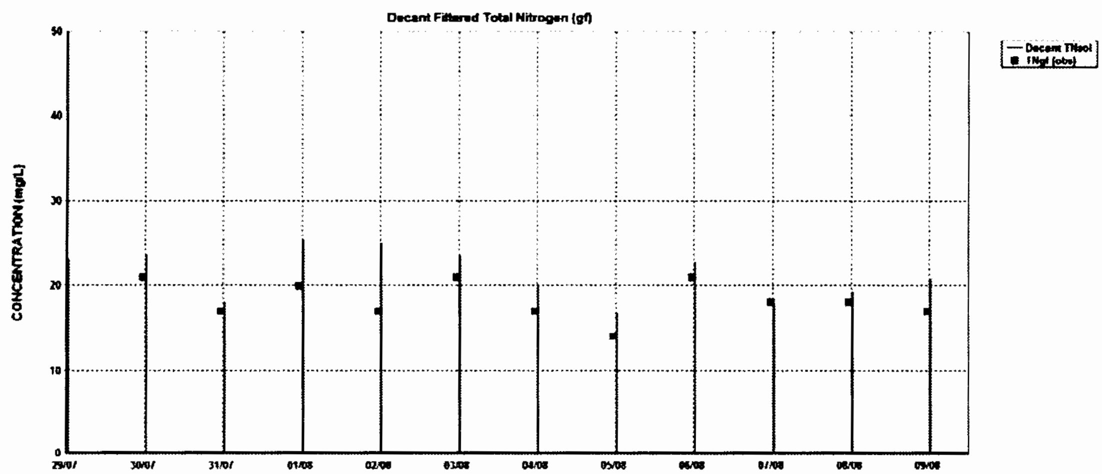
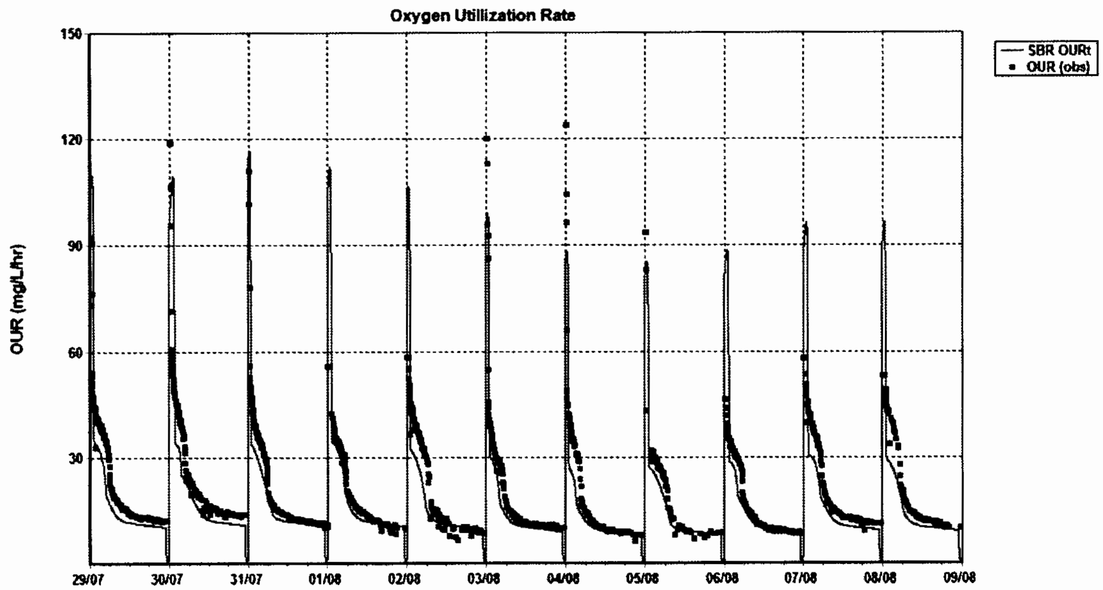


Figure 4-20 Simulated (solid lines) and Observed (points) OURs.



4.9 SLUDGE PRODUCTION

The sludge production yield was used as a further check on the data integrity and additional support for the estimated f_{UP}. The average sludge production in the SBR during the intensive testing period was calculated according to the steps listed below. The average measured values shown in Table 4-10 were used in these calculations.

Table 4-10 Average Measured Values for Intensive Period Used in Sludge Production Calculations

Parameter	Value	Units
Influent COD tot.	732	mg COD/L
Decant COD gf filt.	39.1	mg COD/L
Reactor VSS	1429	mg VSS/L
Decant VSS	78	mg VSS/L

1. Average COD utilized (total influent COD minus filtered effluent COD):

a) $Average\ TCOD_{influent} = 8\frac{L}{d} \times 732\frac{mg}{L} = 5855\frac{mg}{d}$

b) $Average\ SCOD_{effluent} = 10\frac{L}{d} \times 39.1\frac{mg}{L} = 391\frac{mg}{d}$

Subtract a) from b) = $5464 \frac{mg}{d}$

2. Average total sludge production in the waste and effluent streams:

a) $Average\ VSS_{WAS} = 1429 \frac{mg}{L} \times 0.625 \frac{L}{d} = 893 \frac{mg}{d}$

b) $Average\ VSS_{effluent} = (8 - 0.625) \frac{L}{d} \times 78 \frac{mg}{L} = 575 \frac{mg}{d}$

Adding a) and b) = $1468 \frac{mg}{d}$

3. Sludge production per influent biodegradable COD:

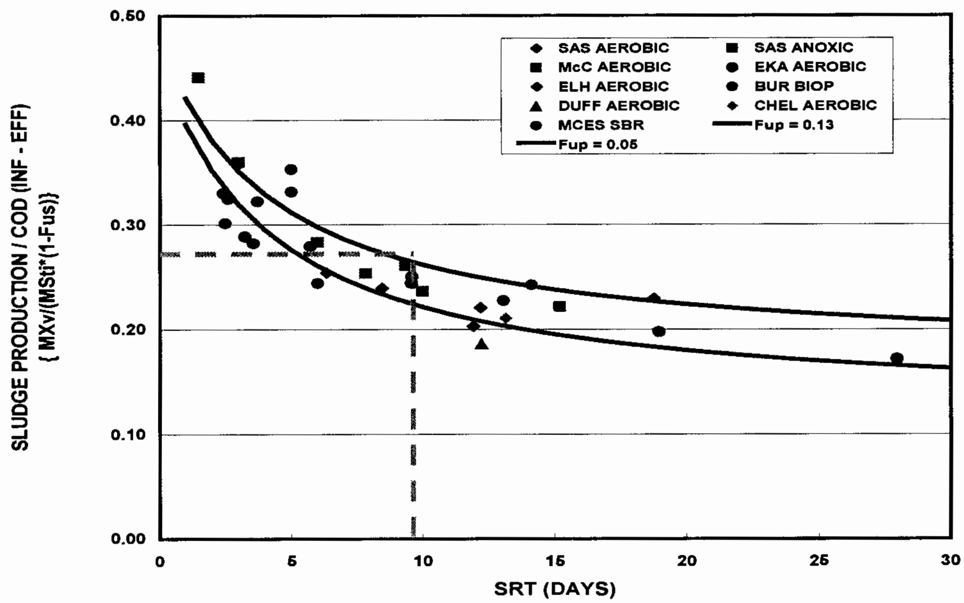
$$= \frac{1468 \frac{mgVSS}{d}}{5464 \frac{mgCOD}{d}} = 0.27\ mgVSS/mgCOD$$

The SRT in the SBR during the intensive testing period is calculated by dividing the average mass of VSS in the SBR by the average total sludge production:

$$= \frac{1429 \frac{mg}{L} \times 10 \frac{L}{d}}{1468 \frac{mgVSS}{d}} = 9.74\ d$$

Figure 4-21 shows a plot of sludge production data from a number of closely controlled systems operated at steady state over a range of SRTs, treating either raw or primary settled wastewater (Dold, 2007). The data are presented in terms of the mass of VSS produced (in the waste and effluent streams) per unit COD utilized (total influent COD minus filtered effluent COD). Also shown are two lines plotted from a sludge production equation presented by Dold, 2007, for unbiodegradable particulate COD fractions (f_{UP}) values of 0.13 and 0.05, representing typical values for raw influent and primary effluent, respectively, and a temperature of 20°C. As previously discussed, the estimated f_{UP} value of the raw influent in the current study is 0.10. Dashed lines marking the SRT and sludge production of the current system, i.e. 9.74 d and 0.27 mg VSS / mg COD, respectively, have been added to Figure 4-21. As can be seen in Figure 4-21, the sludge production measured in the current study is consistent with similar published studies.

Figure 4-21 **Volatile Solids Production versus SRT Compared to a Range of Observed Data (after Dold, 2007).**



4.10 SUMMARY OF MODELING PARAMETERS

The key influent wastewater characteristic parameters are summarized in Table 4-11. The key nitrification kinetic parameters are summarized in Tables 4-12 and 4-13.

Table 4-11 Summary of Key Influent Characteristics

Parameter	Fritz Island WWTP	Typical Raw Influent Value	Typical Primary Settled Influent Value	Units
f_{BS} Fraction of total influent COD that is soluble readily biodegradable	0.21	0.16	0.27	mg COD / mg COD
f_{US} Fraction of total influent COD that is soluble unbiodegradable	0.05	0.05	0.08	mg COD / mg COD
f_{UP} Fraction of total influent COD that is particulate unbiodegradable	0.10	0.13	0.08	mg COD / mg COD
f_{XSP} Particulate fraction of influent slowly biodegradable COD	0.50	0.75	0.5	mg COD / mg COD
f_{NA} Fraction of influent TKN that is ammonia	0.60	0.66	0.75	mg N / mg N
f_{NUS} Fraction of influent TKN that is soluble unbiodegradable	0.03	0.02	0.02	mg N / mg N
f_{NOX} Fraction of influent TKN that is particulate organic	0.50	0.50	0.25	mg N / mg N
f_{PO4} Fraction of influent TP that is soluble phosphate	0.43	0.5	0.75	mg P / mg P
$f_{N,ML}$ Nitrogen content of sludge	0.09	0.10	0.10	mg N / mg VSS
$f_{CV,XS}$ Particulate biodegradable COD/VSS ratio	1.40	1.60	1.60	mg COD / mg VSS
$f_{CV,XI}$ Particulate inert COD/VSS ratio	1.60	1.60	1.60	mg COD / mg VSS

Table 4-12 Summary of Ammonia Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{AOB,20}$ Ammonia oxidizing bacteria maximum specific growth rate	0.62	0.90	d^{-1}
$b_{AOB,20}$ Ammonia oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,AOB,NH4,20}$ Ammonia oxidizing bacteria substrate half-saturation constant (BioWin default, based on WERF, 2003)	0.70	0.70	mg N / L
$\Theta\mu_{AOB}$ Ammonia oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default, based on WERF, 2003)	1.072	1.072	
$\Theta\ b_{AOB}$ Ammonia oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

Table 4-13 Summary of Nitrite Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{NOB,20}$ Nitrite oxidizing bacteria maximum specific growth rate	0.70	0.70	d^{-1}
$b_{NOB,20}$ Nitrite oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,NOB,NO2,20}$ Nitrite oxidizing bacteria substrate half-saturation constant (BioWin default)	0.1	0.1	mg N / L
$\Theta\mu_{NOB}$ Nitrite oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default)	1.06	1.06	
$\Theta\ b_{NOB}$ Nitrite oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

CHAPTER 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The primary objectives of this work were to evaluate the nitrification kinetic parameters (*i.e.* primarily the nitrifier maximum specific growth rates, μ_{AOB} and μ_{NOB}) for a nitrifying activated sludge system treating the Fritz Island WWTP raw wastewater, and to determine the wastewater characteristics of the raw wastewater. This information will be used in sizing the activated sludge process (and related processes) and developing a BioWin model for the Fritz Island WWTP upgrade.

The approach used to estimate the wastewater characteristics and nitrification kinetics of the Fritz Island WWTP influent generally followed the low F:M procedure presented in the Water Environment Research Foundation wastewater characterization report (WERF, 2003). The low F:M protocol involves operating a laboratory-scale sequencing batch reactor (SBR) for several weeks to attain a *quasi* steady-state, and then conducting intensive monitoring over a period of approximately two weeks. Key information derived from the present study is presented in Tables 5-1 through 5-3.

Important conclusions/observations from the study are listed below:

- The raw influent strength is high. The average COD over the 47-day system start-up period was 822 mg/L; the average COD over the 11-day intensive monitoring period was 732 mg/L.
- The raw influent appears to be more soluble in nature than a typical municipal wastewater. This is supported by the following observations:
    - The amount of solids in the wastewater was low relative to the organic strength. The TSS/COD ratio was 0.29 mg TSS / mg COD over the 47-day system start-up and 0.27 mg TSS / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.50 mg TSS /mg COD for a typical raw municipal wastewater.
    - The ratio of glass-fibre filtered COD to total COD was 0.61 mg COD / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.40 mg COD / mg COD for a typical raw municipal wastewater.
    - The ratio of flocculated/filtered COD to total COD was 0.47 mg COD / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.25 mg COD / mg COD for a typical raw municipal wastewater.
    - The soluble ***readily*** biodegradable fraction of the influent was 0.21 mg COD / mg COD, which is higher than the typical value of 0.16 mg COD / mg COD for a raw municipal wastewater.

- The nutrient content of the wastewater is low relative to the organic strength. This is supported by the following observations:
    - The influent TKN to COD ratio was 0.05 mg N / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.10 mg N / mg COD for a typical raw municipal wastewater.
    - The influent total phosphorus to COD ratio was 0.007 mg P / mg COD over the 11-day intensive monitoring period. This ratio is usually around 0.02 mg P / mg COD for a typical raw municipal wastewater.
- The unbiodegradable particulate fraction of the influent total COD (f_{UP}) is 0.10 mg COD / mg COD. This value is lower than the typical value of 0.13 mg COD / mg COD for a raw municipal wastewater and is in fact close to the typical value of 0.08 mg COD / mg COD for a primary settled wastewater.
- Sludge production for the bench-scale activated sludge system operated on Fritz Island raw wastewater was observed to be typical at the estimated SRT of 9.74 d and f_{UP} of 0.10 mg COD / mg COD.
- The nitrification behaviour in the system could be simulated accurately with a μ_{AOB} value of 0.62 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d^{-1}], and a μ_{NOB} value of 0.70 d^{-1} [referenced to 20°C, with an Arrhenius temperature dependency coefficient of 1.072 and an aerobic decay rate of 0.17 d-1]. This μ_{AOB} value is lower than the BioWin default value of 0.9 d^{-1} which is based on nitrification rate tests conducted at numerous North American plants. The observed μ_{AOB} value of 0.62 d^{-1} suggests that the ammonia oxidizing bacteria (AOB) were inhibited in the current study.

Table 5-1 Summary of Key Influent Characteristics

Parameter	Fritz Island WWTP	Typical Raw Influent Value	Typical Primary Settled Influent Value	Units
f_{BS} Fraction of total influent COD that is soluble readily biodegradable	0.21	0.16	0.27	mg COD / mg COD
f_{US} Fraction of total influent COD that is soluble unbiodegradable	0.05	0.05	0.08	mg COD / mg COD
f_{UP} Fraction of total influent COD that is particulate unbiodegradable	0.10	0.13	0.08	mg COD / mg COD
f_{XSP} Particulate fraction of influent slowly biodegradable COD	0.50	0.75	0.5	mg COD / mg COD
f_{NA} Fraction of influent TKN that is ammonia	0.60	0.66	0.75	mg N / mg N
f_{NUS} Fraction of influent TKN that is soluble unbiodegradable	0.03	0.02	0.02	mg N / mg N
f_{NOX} Fraction of influent TKN that is particulate organic	0.50	0.50	0.25	mg N / mg N
f_{PO4} Fraction of influent TP that is soluble phosphate	0.43	0.5	0.75	mg P / mg P
$f_{N,ML}$ Nitrogen content of sludge	0.09	0.10	0.10	mg N / mg VSS
$f_{CV,XS}$ Particulate biodegradable COD/VSS ratio	1.40	1.60	1.60	mg COD / mg VSS
$f_{CV,XI}$ Particulate inert COD/VSS ratio	1.60	1.60	1.60	mg COD / mg VSS

Table 5-2 Summary of Ammonia Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{AOB,20}$ Ammonia oxidizing bacteria maximum specific growth rate	0.62	0.90	d^{-1}
$b_{AOB,20}$ Ammonia oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,AOB,NH4,20}$ Ammonia oxidizing bacteria substrate half-saturation constant (BioWin default, based on WERF, 2003)	0.70	0.70	mg N / L
$\Theta\mu_{AOB}$ Ammonia oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default, based on WERF, 2003)	1.072	1.072	
$\Theta\ b_{AOB}$ Ammonia oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

Table 5-3 Summary of Nitrite Oxidizing Bacteria Kinetic Parameter Set

Parameter	Fritz Island WWTP	BioWin 4.0 Default	Units
$\mu_{NOB,20}$ Nitrite oxidizing bacteria maximum specific growth rate	0.70	0.70	d^{-1}
$b_{NOB,20}$ Nitrite oxidizing bacteria aerobic decay rate	0.17	0.17	d^{-1}
$K_{S,NOB,NO2,20}$ Nitrite oxidizing bacteria substrate half-saturation constant (BioWin default)	0.1	0.1	mg N / L
$\Theta\mu_{NOB}$ Nitrite oxidizing bacteria growth rate Arrhenius temperature coefficient (BioWin default)	1.06	1.06	
$\Theta\ b_{NOB}$ Nitrite oxidizing bacteria decay rate Arrhenius temperature coefficient (BioWin default)	1.029	1.029	

REFERENCES

Bye, C.M., Lacharity, R., Kaya, I., Dold, P.L., Bicudo, J. and R.M. Jones. *Nitrification rate testing for practical design of Kitchener WWTP upgrades.* **Proceedings of the 39th Annual Water Environment Association of Ontario Technical Conference, London, Ontario, Canada, April 18 – 20, 2010.**

Bye, C.M., Jones, R.M., and Dold, P.L. *Pragmatic nitrification inhibition testing for robust plant design.* **Water Environment Federation 85th Annual Conference and Exposition, New Orleans, LA, USA, September 29 - October 3, 2012.**

Dold, P.L. *Quantifying Sludge production in municipal treatment plants.* **Proceedings of the Water Environment Federation 72nd Annual Technical Exhibition & Conference, San Diego, California, USA, October 13-17, 2007.**

Dold, P.L., Jones, R.M., Bye, C.M. (2005) *Importance and measurement of decay rate when assessing nitrification kinetics.* **Water Science & Technology, v 52, n 10-11, 469-477.**

Jones, R.M., Bye, C.M., and Dold, P.L. *Nitrification 101 revisited: significance of multistep nitrification in activated sludge plant design and operation.* **Water Environment Federation 85th Annual Conference and Exposition, New Orleans, LA, USA, September 29 - October 3, 2012.**

Lee, Y., Oleszkiewicz, J. A. *Evaluation of maximum growth and decay rates of autotrophs under different physical and environmental conditions.* **Proceedings of the Water Environment Federation 75th Annual Technical Exhibition & Conference, Chicago, Illinois, USA, September 28 - October 2, 2002.**

Mamais, D., Jenkins, D. and Pitt, P. (1993) *A rapid physical-chemical method for the determination of readily biodegradable soluble COD in municipal wastewater.* **Water Research, v 27, n 1, 195-197.**

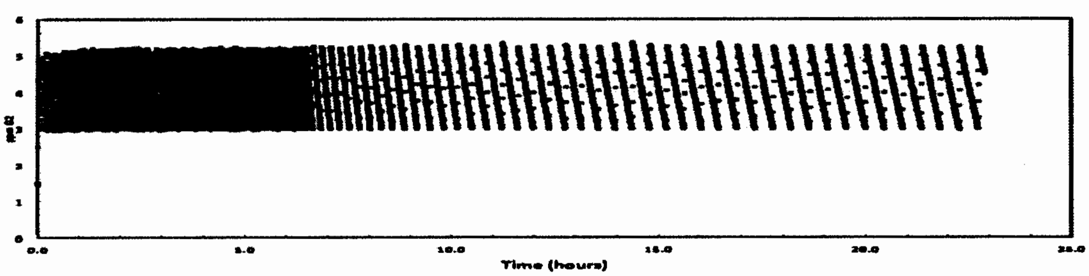
WERF (Water Environment Research Foundation) (2003) *Methods for wastewater characterization in activated sludge modeling.* **Project 99-WWF-3, ISBN 1-893664-71-6. Alexandria, Virginia.**

APPENDIX A

Oxygen uptake rate measurements were conducted ***every day*** from start-up to the end of the study. This is not standard protocol for the WERF Low F/M method; however, it provided data that were useful for identifying the frequency and magnitude of nitrification inhibition events.

During each day of operation, the Dissolved Oxygen (DO) in the bench-scale SBR was maintained between upper and lower setpoints of 3 and 5 mg/L, respectively. An on/off aeration control strategy was used, which resulted in a "sawtooth" DO profile *versus* time throughout the react phase, as shown in Figure A-1 below. Data from the portion of the profile where DO falls from 5 mg/L to 3 mg/L were used to calculate a series of discrete OUR values (*i.e.* slopes from the DO data), and these were plotted against time. An example of an OUR profile over one complete daily react period is shown in Figure A-2. Also shown in the legend of the OUR profile is information on the daily maximum temperature at a nearby weather station over the 24-hour period associated with the SBR feedstock sample corresponding to the OUR profile, and the amount of precipitation that occurred over that period.

Figure A-1 Example Variation in Dissolved Oxygen *versus* Time for a Complete Reaction Period in the Bench-Scale SBR (top) and Over First Two Hours (Bottom).



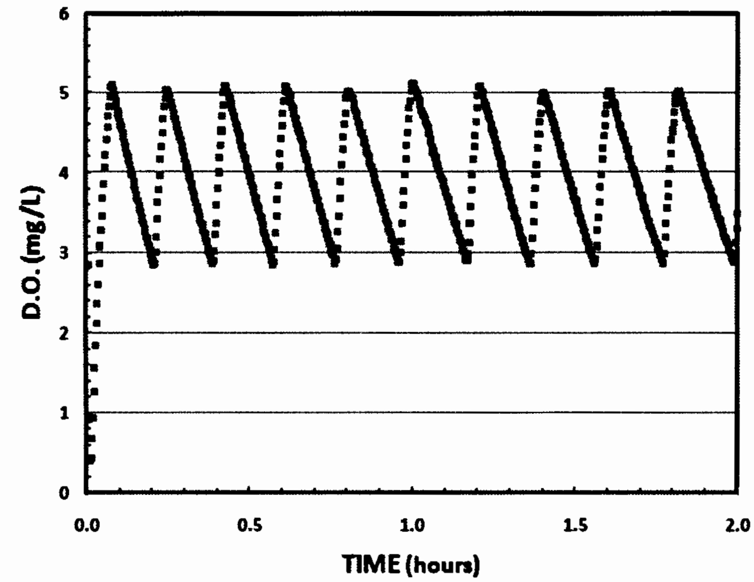
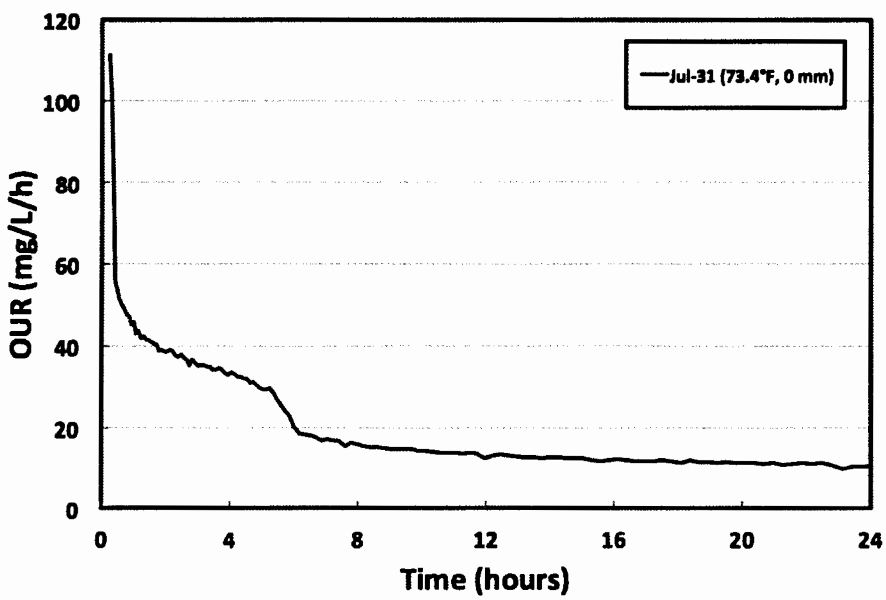


Figure A-2 Typical OUR Profile Derived From Dissolved Oxygen *versus* Time for a Complete Reaction Period in the Bench-Scale SBR.

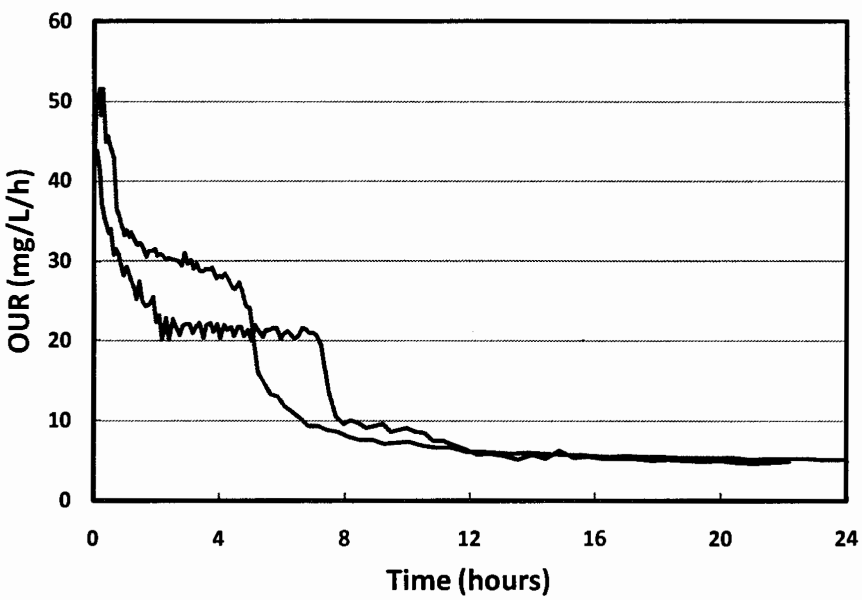


The OUR profile consists of several distinct phases. Initially the OUR is high while soluble readily biodegradable COD is used by heterotrophic organisms. Once this initial phase is complete, the OUR enters a second phase where nitrification is the dominant process in terms of the OUR magnitude. This "plateau" portion typically lasts for several hours until ammonia is fully utilized. During this phase, ammonia is non-limiting, and the OUR is directly related to the product of nitrifier maximum specific growth rate and the mass of nitrifiers in the system. Because of the long sludge age of the bench-scale SBR

(~10 days), the mass of nitrifiers will not change a great deal from day to day; even with some variability in the SBR influent TKN from day to day there will be consistency in the "plateau values" for a series of daily OUR profiles. Therefore, if there ***is*** a significant change in the "plateau OUR" values within a few days, then there has been a significant change in the nitrifier maximum specific growth rates, which in turn implies an inhibitory substance has been introduced to the bench-scale SBR.

Figure A-3 shows an example (***from a similar study conducted at a Canadian plant***) of the OUR "plateau" value dropping over the course of a few days, due to AOB inhibition. The final phase occurs when ammonia becomes depleted and the OUR drops precipitously to lower values. The length of time associated with the occurrence of this drop-off is dependent on the amount of ammonia in the influent feedstock fed to the bench-scale SBR. As such, the time at which the drop-off occurs ***will*** change from day to day.

Figure A-3 Example of OUR "Plateau" Changing from day to day due to Inhibition (after Bye *et al.*, 2012).



Figures A-4 to A-11 below present the OUR profiles for the bench-scale SBR operated at the Fritz Island WWTP. The OUR profiles for the first week of the study are not shown because they contained erroneous data due to poor mixing and high temperatures in the SBR and problems with the DO probe.

Figure A-4 Daily OUR in SBR, June 17th to 23rd, 2013.

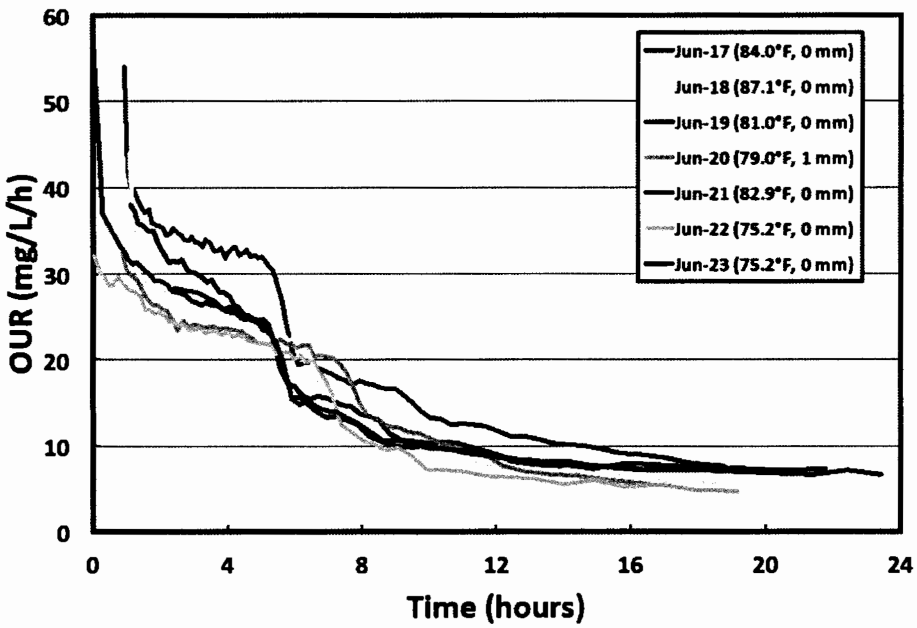


Figure A-5 Daily OUR in SBR, June 24th to 30th, 2013.

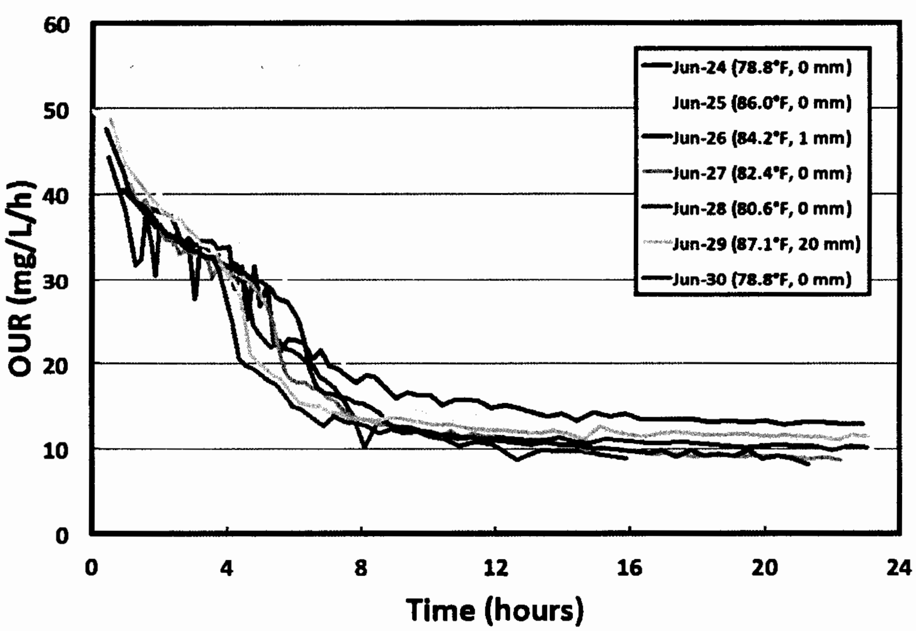


Figure A-6 Daily OUR in SBR, July 1st to 7th, 2013.

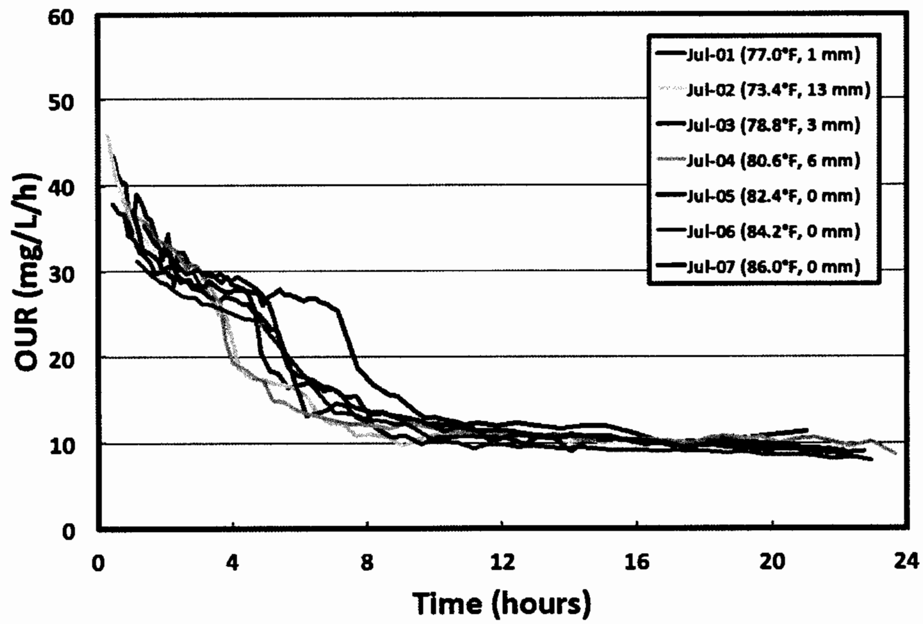


Figure A-7 Daily OUR in SBR, July 8th to 14th, 2013.

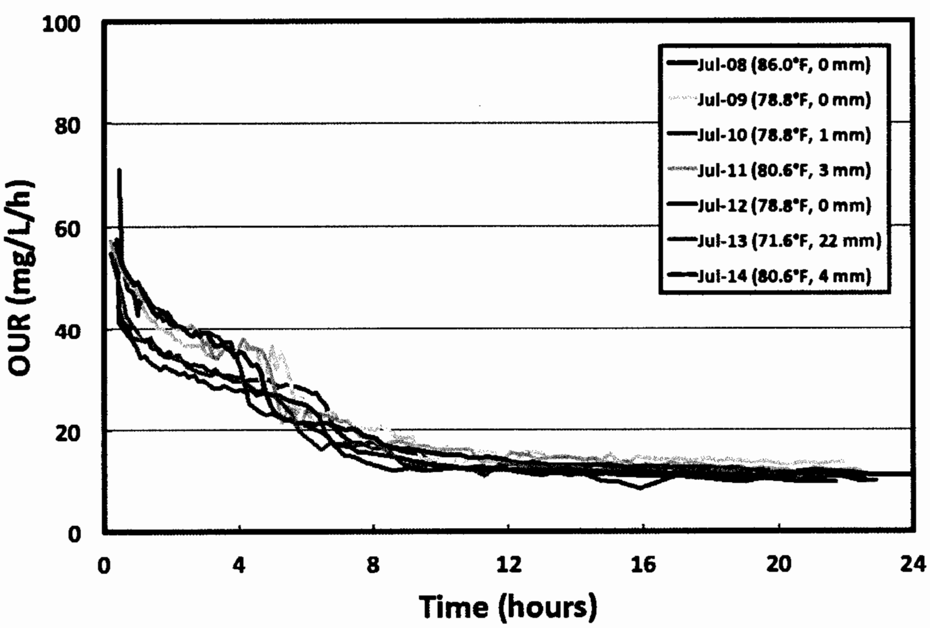


Figure A-8 Daily OUR in SBR, July 15th to 21st, 2013.

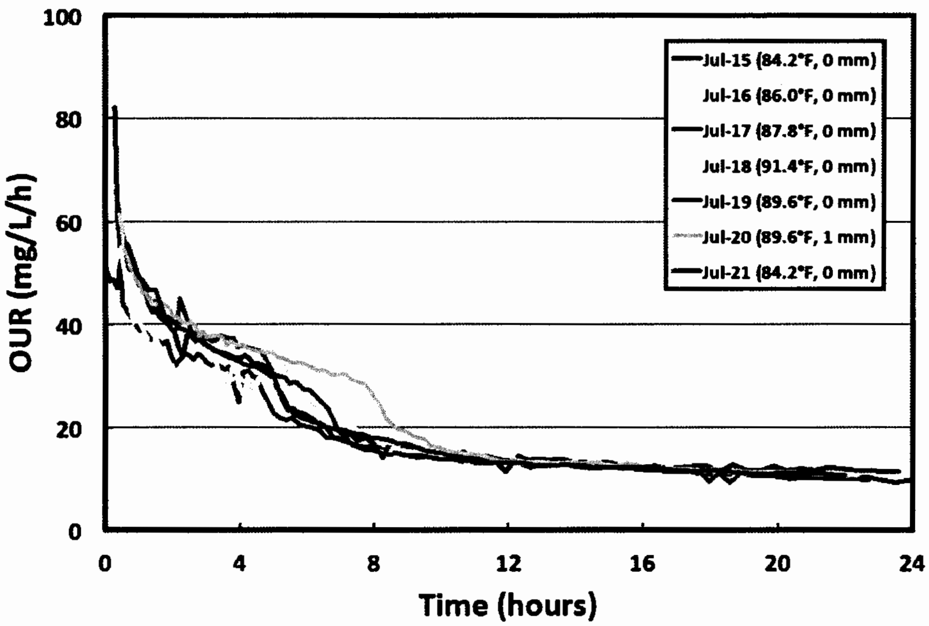


Figure A-9 Daily OUR in SBR, July 22nd to 28th, 2013.

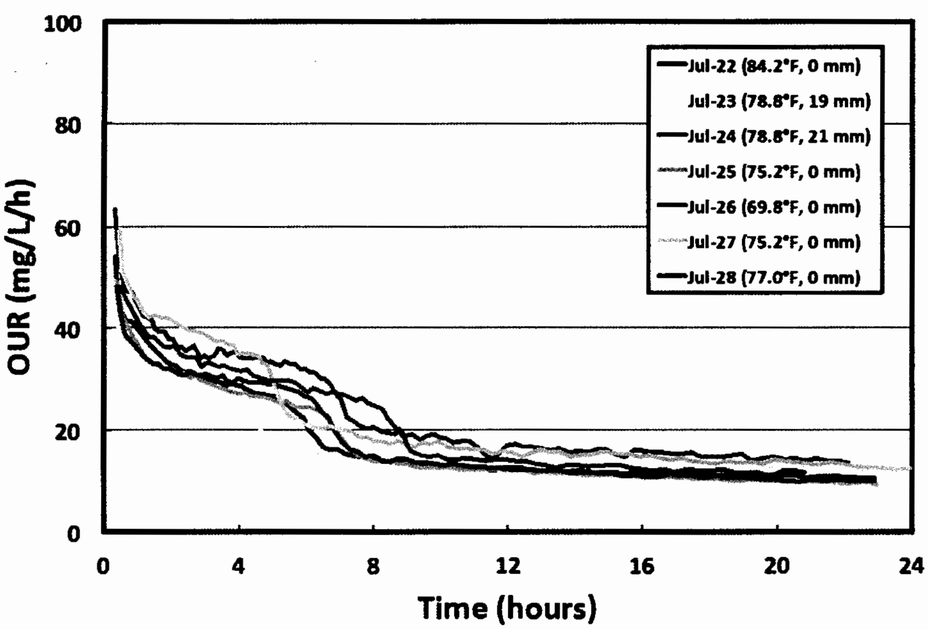


Figure A-10 Daily OUR in SBR, July 29th to August 4th, 2013.

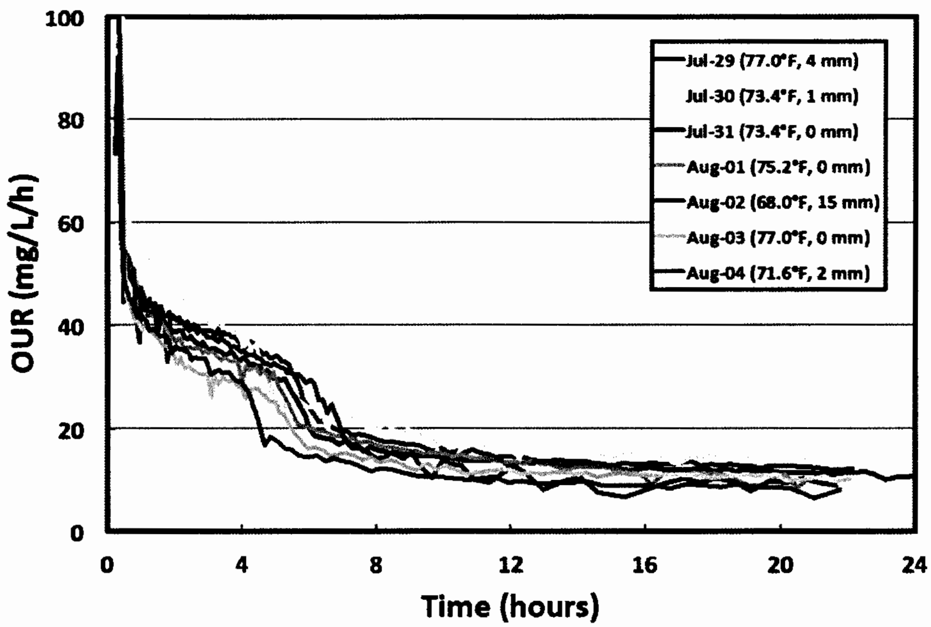
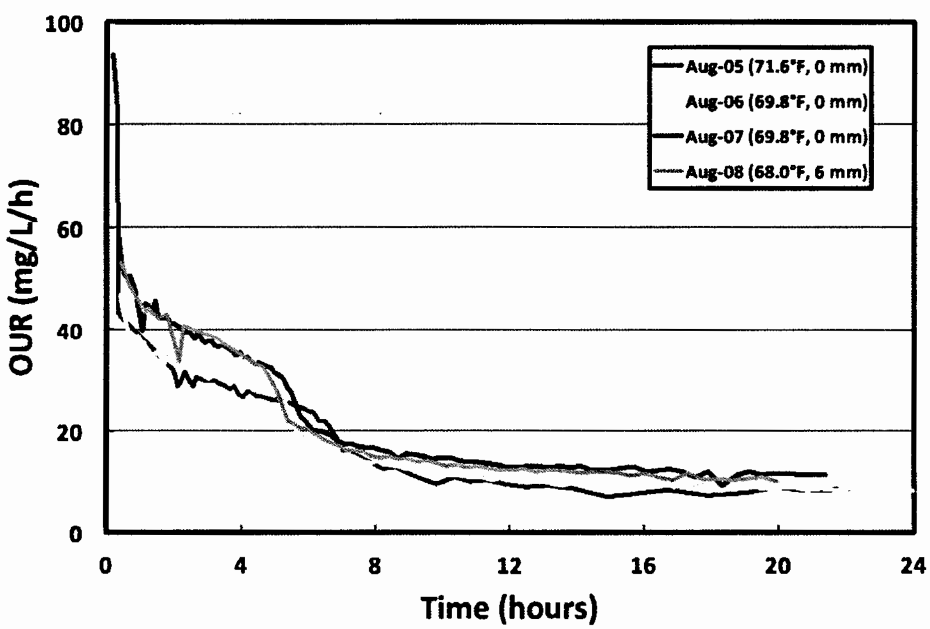


Figure A-11 Daily OUR in SBR, August 5th to 8th, 2013.



PART A - EFFLUENT LIMITATIONS, MONITORING, RECORDKEEPING AND REPORTING REQUIREMENTS

I. A. For Outfall 001, **Latitude** 40° 18' 13", **Longitude** 75° 55' 13", **River Mile Index** 72.8, **Stream Code** 0833

Receiving Waters: Schuylkill River

Type of Effluent: Domestic wastewater (and industrial user wastewater)

1. The permittee is authorized to discharge during the period from December 1, 2013 through November 30, 2018.

2. Based on the anticipated wastewater characteristics and flows described in the permit application and its supporting documents and/or amendments, the following effluent limitations and monitoring requirements apply (see also Additional Requirements and Footnotes).

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) (1)		Concentrations (mg/L)				Minimum (2) Measurement Frequency	Required Sample Type
	Average Monthly	Daily Maximum	Minimum	Average Monthly	Daily Maximum	Instant. Maximum		
Flow (MGD)	Report	Report	XXX	XXX	XXX	XXX	Continuous	Measured
pH (S.U.)	XXX	XXX	6.0	XXX	XXX	9.0	1/day	Grab
Dissolved Oxygen	XXX	XXX	5.0	XXX	XXX	XXX	1/day	Grab
Total Residual Chlorine	XXX	XXX	XXX	0.4	XXX	1.3	1/shift	Grab
Color (Pt-Co Units)	XXX	XXX	XXX	186	XXX	465	1/day	24-Hr Composite
$CBOD_5$ May 1 - Oct 31	3,248	4,958 Wkly Avg	XXX	19	29 Wkly Avg	38	1/day	24-Hr Composite
$CBOD_5$ Nov 1 - Apr 30	4,103	6,154 Wkly Avg	XXX	24	36 Wkly Avg	48	1/day	24-Hr Composite
BOD_5 Raw Sewage Influent	Report	XXX	XXX	Report	XXX	XXX	1/day	24-Hr Composite
Total Suspended Solids Raw Sewage Influent	Report	XXX	XXX	Report	XXX	XXX	1/day	24-Hr Composite
Total Suspended Solids	5,129	7,694 Wkly Avg	XXX	30	45 Wkly Avg	60	1/day	24-Hr Composite
Total Dissolved Solids	XXX	XXX	XXX	1,000	XXX	XXX	1/week	24-Hr Composite
Total Dissolved Solids	XXX	XXX	XXX	XXX	XXX	2000	1/week	Grab

Outfall 001, Continued (from December 1, 2013 through November 30, 2018)

Parameter	Effluent Limitations						Monitoring Requirements	
	Mass Units (lbs/day) [(1)]		Concentrations (mg/L)				Minimum [(2)] Measurement Frequency	Required Sample Type
	Average Monthly	Daily Maximum	Minimum	Average Monthly	Daily Maximum	Instant. Maximum		
Fecal Coliform (CFU/100 ml) May 1 - Sep 30	XXX	XXX	XXX	200 Geo Mean	XXX	1,000	1/day	Grab
Fecal Coliform (CFU/100 ml) Oct 1 - Apr 30	XXX	XXX	XXX	2,000 Geo Mean	XXX	10,000	1/day	Grab
Ammonia-Nitrogen May 1 - Oct 31	1,111	XXX	XXX	6.5	XXX	13	1/day	24-Hr Composite
Ammonia-Nitrogen Nov 1 - Apr 30	3,248	XXX	XXX	19	XXX	38	1/day	24-Hr Composite
Total Kjeldahl Nitrogen	XXX	Report	XXX	XXX	Report	XXX	1/month	24-Hr Composite
Nitrate-Nitrite as N	XXX	Report	XXX	XXX	Report	XXX	1/month	24-Hr Composite
Total Nitrogen	XXX	Report	XXX	XXX	Report	XXX	1/month	Calculation
Total Phosphorus	XXX	Report	XXX	XXX	Report	XXX	1/month	24-Hr Composite
PCBs (Dry Weather) (ng/L)	XXX	XXX	XXX	XXX	Report	XXX	1/year	24-Hr Composite
PCBs (Wet Weather) (ng/L)	XXX	XXX	XXX	XXX	Report	XXX	1/year	24-Hr Composite

Samples taken in compliance with the monitoring requirements specified above shall be taken at the following location(s):

at discharge from facility

Figure 8-1

Liquid Stream Hybrid Option H-2
Pending Permit Conditions

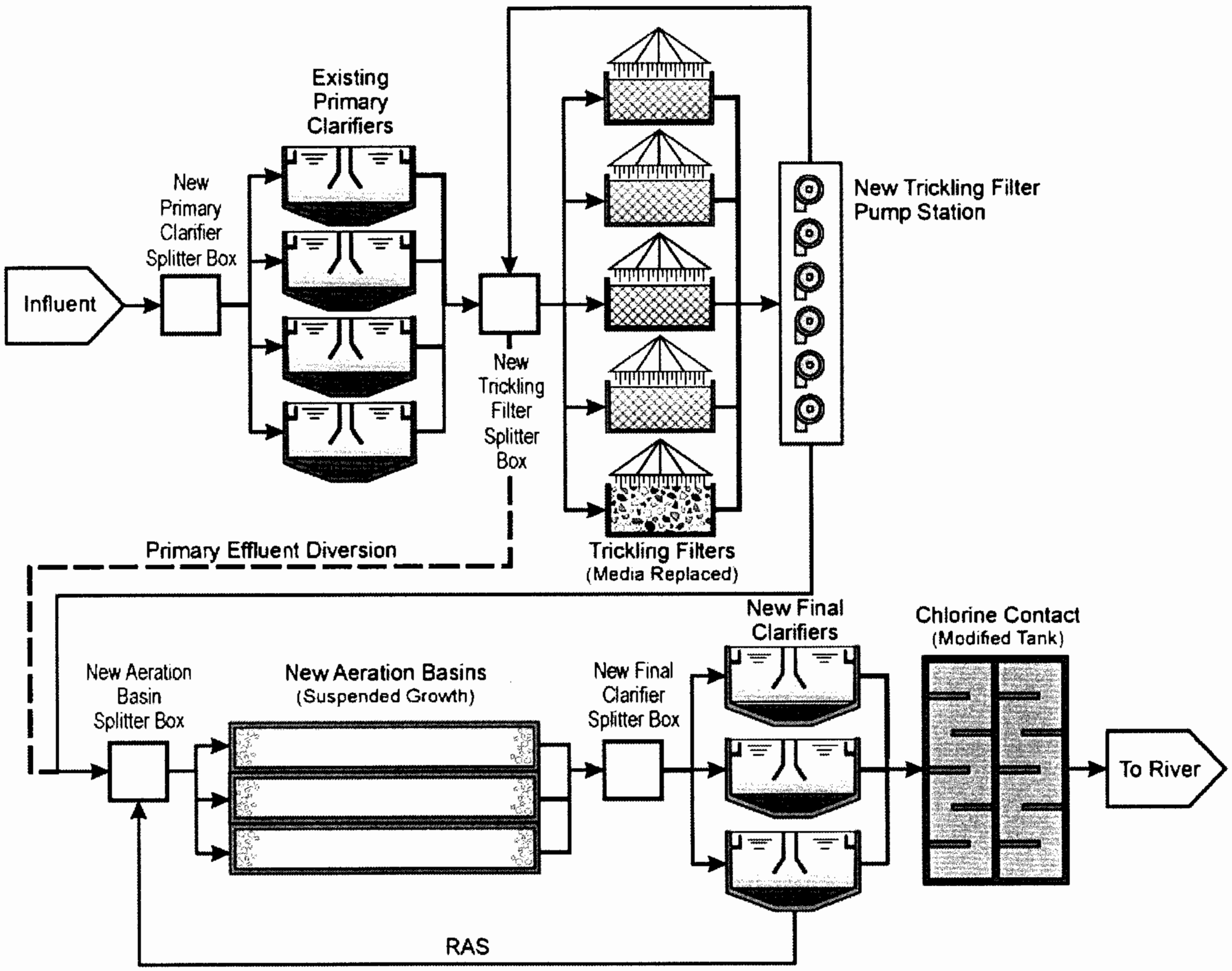
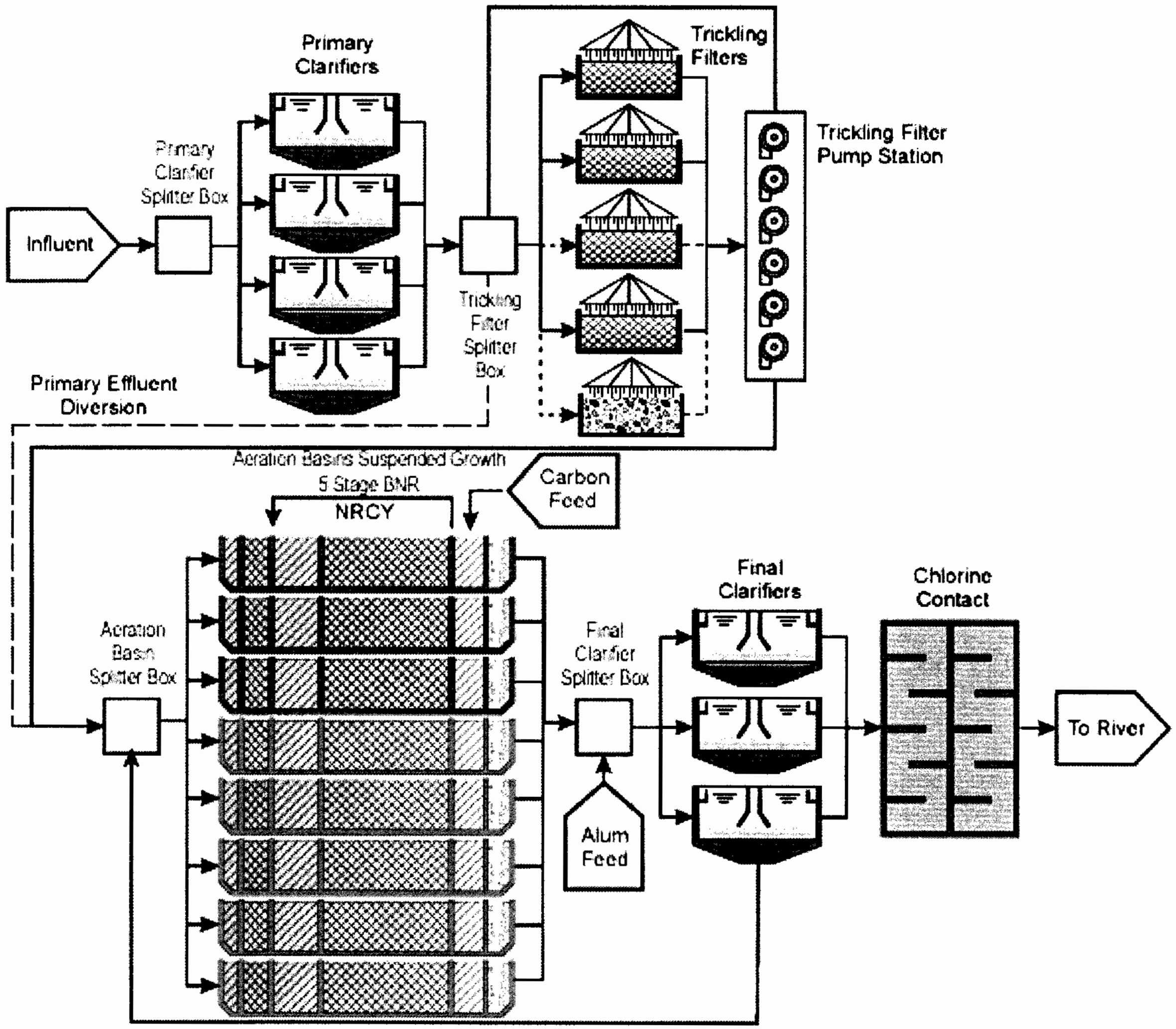
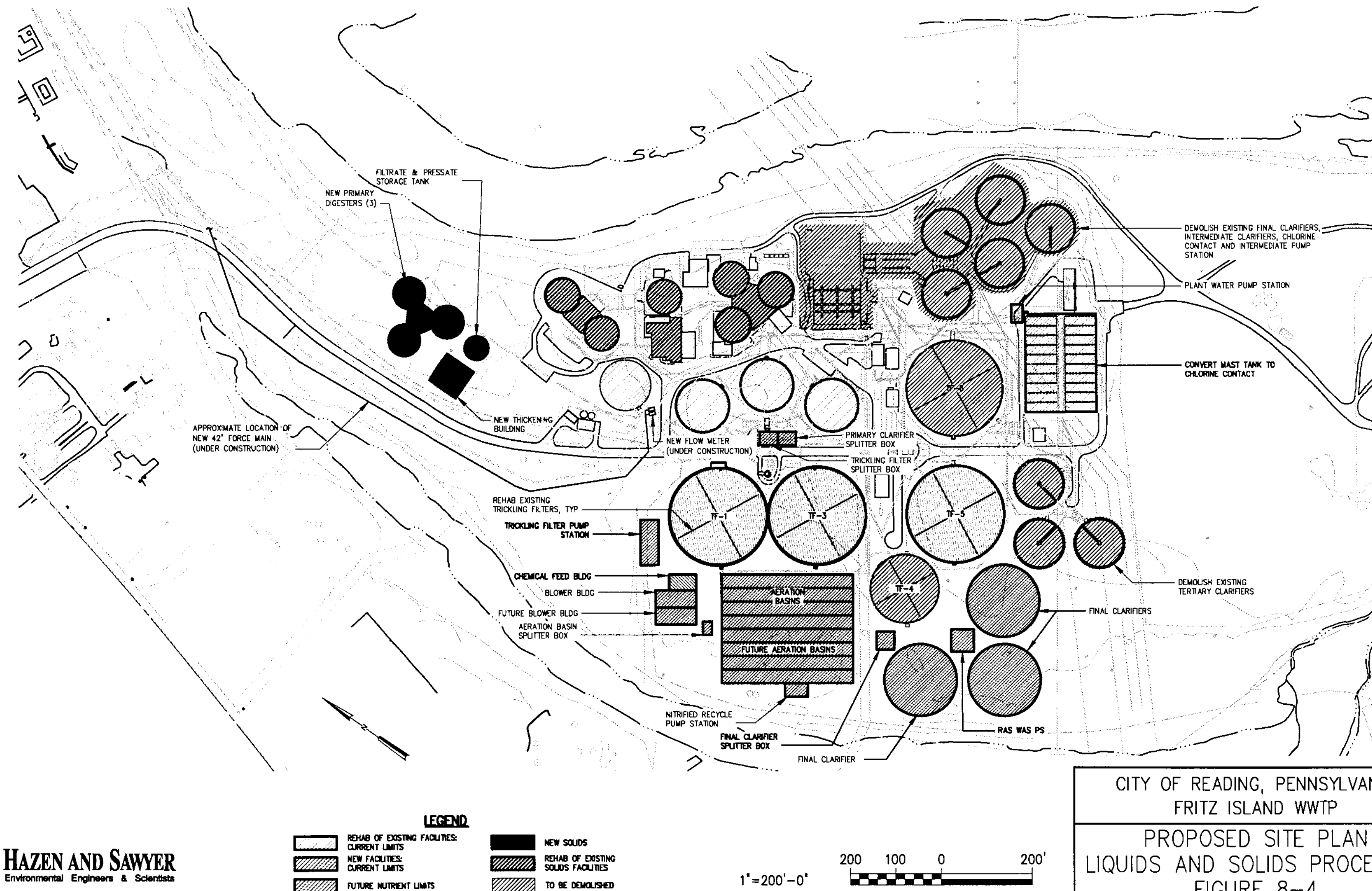


Figure 8-2

Liquid Stream Hybrid Option H-2
Future Nutrient Removal Conditions





HAZEN AND SAWYER
Environmental Engineers & Scientists

CITY OF READING, PENNSYLVANIA
FRITZ ISLAND WWTP

PROPOSED SITE PLAN
LIQUIDS AND SOLIDS PROCESSES
FIGURE 8-4

20120430 6:04P O:\90027-000-PHL\Drawings\Figures\4.27.12 Updates\Combined Site Layout- H-2 and Alt1\Combined H-2 and Alt1.dwg By:JNAUMICK Last Saved By: jnaumick

BRENTWOOD
INDUSTRIES

11/26/2013 WATER TECHNOLOGY GROUP

Technical Data Summary (1)

PROJECT:	City of Reading WWTP_1 of 3 TFs in parallel
ENGINEERING FIRM:	RK&K
ENGINEERS NAME:	
REPRESENTATIVE FIRM:	Geiger Pump and Equipment Co ph:
REPRESENTATIVE:	fax:
PROJECT DESCRIPTION:	A new circular-trickling-filter tower design is proposed using CF/S-3000 media for CBOD Removal Only. Tower depth is 5(ft) and tower plan view is 212 (ft) dia. The influent flow rate to this filter is 6.83 mgd, CBOD load would average 80.67 lbs/10^3 ft3-day, and the wetting rate 0.27 gal/ft2-min, design temperature was 9 deg. C., Unclarified effluent result

Wastewater Influent & Effluent Data:	PRIMARY-TREATED DOMESTIC WW	Filter Influent	Required Effluent	Unclar. Eff. (Clar.Eff.)	Est. Eff. Filtered
Wastewater Type:		Domestic Wastewater			
Flow, mgd (l/sec.):	6.83 (299.24)				
CBOD5 (mg/l):	249	249	n/a	184 (50.7)	41.1
NH3-N (mg/l):	41.4	41.4	n/a	34.5	
TSS (mg/l):	73	73	n/a	222 (15)	
Filter System Configuration:	**T-F Stage #1**				
Treatment Objective	BOD Removal				
No. of Trains	1				
No.of Filters	1				
System Configuration					
1 Filter	**Tower Diameter**	**Depth (ft)**	**Media Type**	**A_s**	**Volume**
Tower Dimensions, ft (m):	212 (64.6)	5 (1.5)	CF/S-3000	31 ft2/ft3 (102) m2/m3	175933 ft3 (4982 m3)
			Total Volume of Tower(s):		**175933 (ft3)**
Process Information:	**T-F Stage 1**				
Purpose of Biological Filter:	CBOD,R				
Design Temp., deg. F (deg. C):	48.2 (9)				
Recycle Ratio (R):	1.00				
Hydraulic Load, (Qt, gpm/ft2 (l/m2-sec)):	0.27 (0.18)				
Org. Load, lbs/10^3ft3-day (kg/m3-day):	80.67 (1.29)				
NH3-N Load, lbs/day (kg/day):	2360 (1071)				
NH3-N Load, lbs/10^3ft3-day (gms/m3-day):	13.412 (215.29)				
NH3-N, R Cap. at Conditions, lbs/day (kg/day):	0 (0)				
NH3-N, T-F Eff, lbs/day:	1968 (895)				
Vent Rate Each Filter, ft3/min (m3/min) =	25129 (712)				
Process Load Data:	**T-F Stage 1**				
Raw WW Load/system, lbs/day (kg/day):	14192 (6451)				
CBOD Load/Trickling Filter, lbs/day (kg/day):	14192 (6451)				
CBOD Removed in T-F, lbs/day (kgs/day):	11303 (5138)				
CBOD, T-F effluent, lbs/day (kg/day):	2889 (1313)				

(1) These calculations are completed as a courtesy. Brentwood Industries does not provide nor accept any responsibility for performance or process warranties as part of this offering, whether expressed or implied. We recommend that a professional engineer provide detailed structural and process designs.

BRENTWOOD
INDUSTRIES

6/25/2013 WATER TECHNOLOGY GROUP

Technical Data Summary [(1)]

PROJECT: City of Reading WWTP_1 of 3 TFs in parallel
ENGINEERING FIRM: RK&K
ENGINEERS NAME:
REPRESENTATIVE FIRM: select rep name above, select rep name above — ph: select rep name above
REPRESENTATIVE: SELECT REPRESENTATIVES NAME — fax: select rep name above
PROJECT DESCRIPTION: A new circular-trickling-filter tower design is proposed using CF/S-3000 media for CBOD Removal Only. Tower depth is 5(ft) and tower plan view is 212 (ft) dia. The influent flow rate to this filter is 6.83 mgd, CBOD load would average 101.73 lbs/10^3 ft3-day, and the wetting rate 0.27 gal/ft2-min, design temperature was 9 deg. C., Unclarified effluent result

Wastewater Influent & Effluent Data:	PRIMARY-TREATED DOMESTIC WW	Filter Influent	Required Effluent	Unclar. Eff. (Clar.Eff.)	Est. Eff. Filtered
Wastewater Type:		Domestic Wastewater			
Flow, mgd (l/sec.):	6.83 (299.24)				
CBOD5 (mg/l):	314	314	n/a	267 (72.3)	62.1
NH3-N (mg/l):	47.9	47.9	n/a	39.6	
TSS (mg/l):	109	109	n/a	306 (15.3)	
Filter System Configuration:	**T-F Stage #1**				
Treatment Objective	BOD Removal				
No. of Trains	1				
No.of Filters	1				
System Configuration					
1 Filter	**Tower Diameter**	**Depth (ft)**	**Media Type**	**A_s**	**Volume**
Tower Dimensions, ft (m):	212 (64.6)	5 (1.5)	CF/S-3000	31 ft2/ft3 (102) m2/m3	175933 ft3 (4982 m3)
			Total Volume of Tower(s):		**175933 (ft3)**
Process Information:	**T-F Stage 1**				
Purpose of Biological Filter:	CBOD,R				
Design Temp., deg. F (deg. C):	48.2 (9)				
Recycle Ratio (R):	1.00				
Hydraulic Load, (Qt, gpm/ft2 (l/m2-sec)):	0.27 (0.18)				
Org. Load, lbs/10^3ft3-day (kg/m3-day):	101.73 (1.63)				
NH3-N Load, lbs/day (kg/day):	2730 (1239)				
NH3-N Load, lbs/10^3ft3-day (gms/m3-day):	15.518 (249.1)				
NH3-N, R Cap. at Conditions, lbs/day (kg/day):	0 (0)				
NH3-N, T-F Eff, lbs/day:	2256 (1026)				
Vent Rate Each Filter, ft3/min (m3/min) =	28744 (814)				
Process Load Data:	**T-F Stage 1**				
Raw WW Load/system, lbs/day (kg/day):	17897 (8135)				
CBOD Load/Trickling Filter, lbs/day (kg/day):	17897 (8135)				
CBOD Removed in T-F, lbs/day (kgs/day):	13773 (6260)				
CBOD, T-F effluent, lbs/day (kg/day):	4123 (1874)				

(1) These calculations are completed as a courtesy. Brentwood Industries does not provide nor accept any responsibility for performance or process warranties as part of this offering, whether expressed or implied. We recommend that a professional engineer provide detailed structural and process designs.

Prepared for: Robert J. Andryszak, PE
Director, Wastewater
RK&K

Prepared by: Christopher M. Bye, Ph.D., P.Eng.
Senior Process Engineer
EnviroSim Associates Ltd.

Date: October 24, 2013

Subject: Preliminary BioWin Modeling of Fritz Island WWTP Upgrade

This technical memorandum summarizes the findings of preliminary modeling performed for the City of Reading Fritz Island WWTP upgrade. It refers to two BioWin files:

1. **3 Tanks – 12 deg C.bwc**: This BioWin file uses influent wastewater characteristics and ammonia oxidizing bacteria growth rates determined through work performed by EnviroSim at the WWTP during the summer of 2013.
2. **3 Tanks – 12 deg C – Normal AOB 8 d SRT.bwc**: This BioWin file uses influent wastewater characteristics determined through work performed by EnviroSim at the WWTP during the summer of 2013 but assumes a more "typical" nitrification rate in accordance with previous modeling activities performed by other parties.

Key Model Inputs

A crucial aspect of any BioWin model is the fractionation of the typically measured parameters such as COD, BOD, and TKN into sub-components. These sub-components are referred to as wastewater characteristics. The determination of the wastewater characteristics used for the preliminary modeling is discussed in detail in the report prepared by EnviroSim that was included as an appendix to RK&K's recent liquid process technical memorandum. Two important findings included:

1. The raw influent to the Fritz Island WWTP contains a higher than typical amount of soluble biodegradable material.
2. The raw influent to the Fritz Island WWTP contains a slightly lower than typical amount of particulate unbiodegradable material (commonly referred to as "non-biodegradable VSS, or nbVSS).

Another important aspect of any BioWin model are the growth rates of nitrifying organisms responsible for the transformation of influent ammonia to nitrate (*via* nitrite); both the ammonia oxidizing bacteria (AOB) and nitrite oxidizing bacteria (NOB). Again, the determination of these kinetic constants is discussed in detail in the report prepared by EnviroSim that was included as an appendix to RK&K's recent liquid process technical memorandum. An important finding was that the AOB exhibited a lower than typical maximum specific growth rate of 0.62 d^{-1} when exposed to Fritz Island influent wastewater.

BioWin Results – "3 Tanks – 12 deg C.bwc"

This BioWin file takes selected input design concentrations and flow, along with the experimentally determined wastewater characteristics, and routes them through a primary settling tank element with an equivalent surface area to the planned four primary settling tanks. A 65% solids capture is used in this BioWin element. The primary effluent is then flows to a trickling filter element with an equivalent surface area to the planned upgraded trickling filters 1, 3, and 5. The media characteristics (*e.g.* specific media area on a ft^2 per ft^3 of media basis) are based on Brentwood structured cross-flow media. A flow-splitting element is used to induce a recycle flow of twice the primary effluent flow. The trickling filter effluent leaves the vertical branch of the flow-splitting element and is directed to the activated sludge process. The total volume (4.5 million gallons) of activated sludge tankage for the planned update is split into three bioreactor elements to simulate a degree of plug flow within the tanks. Mixed liquor flows out of the last bioreactor zone and into a secondary clarifier element. This type of secondary clarifier element assumes a solids capture rate of 99.8%, and returns RAS to the first bioreactor element at 100% of the plant raw influent flow. Sludge wasting is conducted *via* a flow splitting element located on the RAS line; the waste sludge flow has been selected such that the solids retention time (SRT) of the activated sludge tanks is 12 days. A screenshot of the BioWin model flowsheet is shown in Figure 1 below.

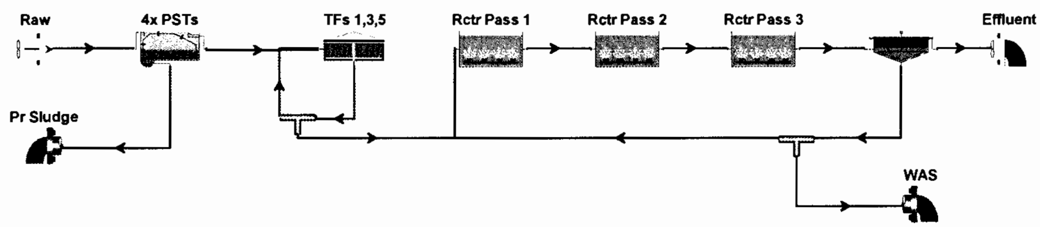


FIGURE 1: Flowsheet for preliminary BioWin model "3 Tanks – 12 deg C.bwc".

Two points to note are:

1. The model has not yet been refined to include solids processing units and their resulting recycle streams. It is anticipated that including recycle streams will add a small amount to the overall solids inventory that must be carried by the activated sludge system.
2. The SRT of 12 days is longer than the 8 days used for BioWin modeling in the Act 537 study, and is a contributing factor to the discrepancy in activated sludge tankage requirements that is under review. A longer SRT is required to achieve effluent ammonia in the region of 1 mg/L because of the lower AOB growth rate observed by EnviroSim. However, the other BioWin file to be discussed in this technical memorandum will show that this is not the primary reason for the discrepancy.

The preliminary modeling of the upgraded tankage indicates that a greater aeration tank volume than 4.5 million gallons will be required to achieve mixed liquor suspended solids (MLSS) in the region of 3,500 mg/L. The model indicates that if the tankage remains at 4.5 million gallons the MLSS will be in the region of 6,000 mg/L. As mentioned above, a contributing factor to this is the requirement of a longer SRT arising from the lower nitrification rate determined in the summer of 2013. However, another major contributing factor is the predicted suspended solids from the trickling filter.

At the moment there are three values under review:

1. In the Act 537 modeling performed previously, a value of 50 mg/L was used for the trickling filter effluent suspended solids.
2. Brentwood design documents recommended that a value of approximately 300 mg/L be used.
3. The preliminary BioWin modeling discussed in this technical memorandum indicates a trickling filter effluent suspended solids in the region of 200 mg/L.

The BioWin file that accompanies this technical memorandum (**3 Tanks – 12 deg C.bwc**) currently predicts a trickling filter effluent solids concentration of 223 mg/L. A number of model runs have been conducted to investigate the sensitivity of this value to different model parameters such as hydrolysis rates, biofilm detachment rates, and biofilm diffusivity constants. The predicted trickling filter effluent suspended solids tends to remain in the region of 200 mg/L for the various model parameters investigated to date. What tends to vary is the *makeup of the trickling filter effluent solids.* That is, the trickling filter effluent solids are largely comprised of (a) organisms grown on BOD within the filter, and (b) undegraded particulate BOD leaving the filter. The aeration tank MLSS does not vary a great deal depending on this makeup.

Two model parameters related to the trickling filter performance have been changed from default values in the BioWin file **3 Tanks – 12 deg C.bwc**. These include:

1. The hydrolysis rate of particulate material in the trickling filter has been increased slightly from the default value of 2.1 d^{-1} to 2.5 d^{-1}. This tends to increase the amount of particulate BOD removed across the trickling filter and increases the proportion of organisms in the trickling filter effluent suspended solids.
2. The biofilm detachment rate has been decreased from the default value of $8x10^4$ g/m^3*d to $3x10^4$ g/m^3*d. This tends to retain particulate matter in the trickling filter longer than would be the case with default values.

The resulting yield on a lbs VSS per lb BOD basis is 0.78 lbVSS/lb BOD, as shown in the yellow bar of Figure 2 below.

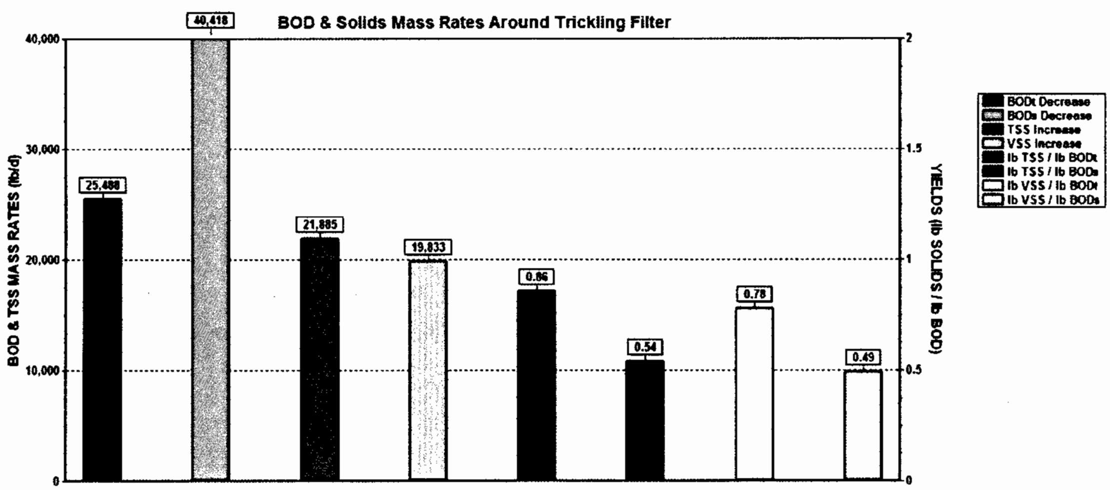


FIGURE 2: BioWin chart showing TSS and VSS yields for total and soluble BOD removal basis.

The predicted solids yield of 0.78 lbVSS/lb BOD agrees with values observed in Table 4-7 from Section 4.3.3.1 of the US EPA Process Design Manual for Sludge Treatment and Disposal (document EPA 625/1-79-011) obtained from Brentwood Industries. Of particular interest in this table are the results from the Stockton, CA WWTP because of the footnote associated with its sludge yields which indicates it receives heavy loading periods from vegetable and fruit canneries. It is possible that the Stockton WWTP has a high soluble BOD component such as that observed at the City of Reading's Fritz Island WWTP.

Also germane to the discussion of trickling filter effluent suspended solids are the fate of two non-biodegradable components originating from the raw influent wastewater. These are:

1. Inert inorganic suspended solids (ISS), that is, the difference between raw influent TSS and VSS, and;
2. Influent non-biodegradable VSS (nbVSS).

A portion of each of these is removed across the primary settling tank. The remainder that is not captured by the primary settling tank enters the downstream biological processes and is not degraded biologically. These two components accumulate in the mixed liquor and only leave the process *via* the wastage stream. Accumulated ISS in an activated sludge process largely makes up the difference between the MLSS and MLVSS. Accumulated nbVSS contributes to the MLVSS. Figure 3 below shows that the total concentration of these two components in the primary and trickling filter effluent is predicted to be 32 mg/L. The concentration of these components is a direct consequence of the experimentally determined wastewater characteristics and is independent of other factors such as trickling filter solids yields that are currently under review.

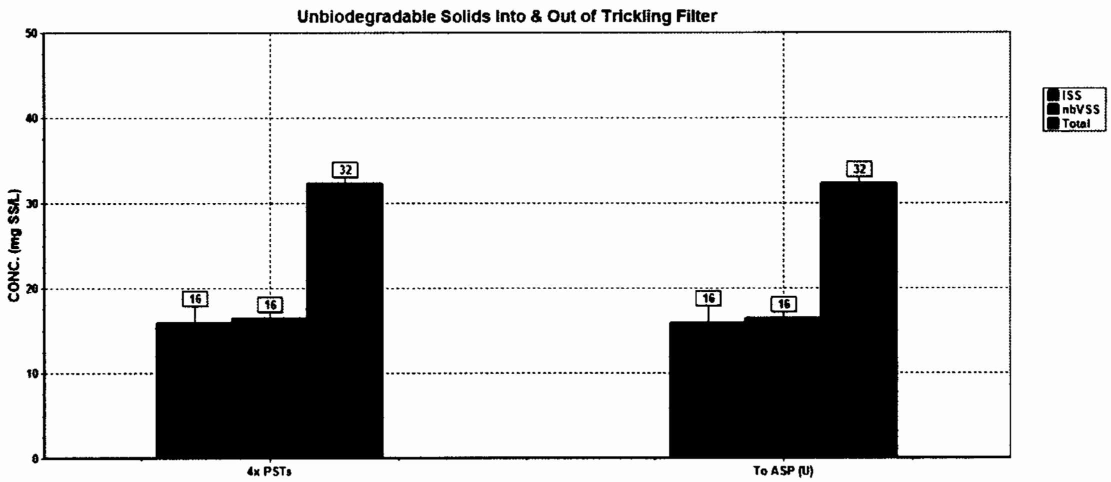


FIGURE 3: BioWin chart showing influent inert components entering and leaving the trickling filter.

BioWin Results – "3 Tanks – 12 deg C – Normal AOB 8 d SRT.bwc"

This BioWin file is identical to the BioWin file **3 Tanks – 12 deg C.bwc** with one exception: the BioWin default value of 0.9 d^{-1} was input for the AOB maximum specific growth rate instead of the lower value measured by EnviroSim during the summer of 2013. This allows the simulation of a shorter SRT (8 days) to achieve effluent ammonia of less than 1 mg/L. This was done to explore the impact of the longer SRT used in the previously discussed BioWin model on the predicted MLSS. The flowsheet is identical to the one discussed above and is therefore not outlined in this section.

The preliminary modeling of the upgraded tankage using a default typical value for the AOB maximum specific growth rate also indicates that a greater aeration tank volume than 4.5 million gallons will be required to achieve mixed liquor suspended solids (MLSS) in the region of 3,500 mg/L. The model indicates that if the tankage remains at 4.5 million gallons the MLSS will be in the region of 4,700 mg/L. That is, even with a lower SRT of 8 days, the mixed liquor is 1,200 mg/L over the design target of 3,500 mg/L.

ATTACHMENT – Section 4.3 of EPA DESIGN MANUAL

Refer to Section 4.3.3.1 of attached EPA Design Manual.

EPA 625/1-79-011

PROCESS DESIGN MANUAL
FOR
SLUDGE TREATMENT AND DISPOSAL

U.S. ENVIRONMENTAL PROTECTION AGENCY

Municipal Environmental Research Laboratory
Office of Research and Development

Center for Environmental Research Information
Technology Transfer

September 1979

Activated sludge also contains filamentous microorganisms such as Sphaerotilus, Thiothrix, Bacillus, and Beggiatoa (62). Various protozoa are present, including ciliates and flagellates.

4.3.3 Trickling Filters

Trickling filters are widely used in municipal wastewater treatment. This section covers trickling filters that are used with clarifiers. When a clarifier is not used, the trickling filter effluent is usually fed to an activated sludge process. Refer to Section 4.3.5 for such combinations.

4.3.3.1 Computing Trickling Filter Sludge Production - Dry Weight Basis

Trickling filter microorganisms are biochemically similar to microorganisms that predominate in activated sludge systems. Consequently, solids production from trickling filters and from activated sludge systems is roughly similar when compared on the basis of pounds of solids produced per pound of substrate removed. There are differences between the two systems, however, with respect to solids production prediction methodology and the pattern of sludge wasting. Attempts have been made to develop solids production models consistent with biological theory (47,63,64). However, presently (1979), empirical methods are usually used for design purposes. Table 4-7 presents sludge yields observed at several treatment plants and from one long-term pilot study. These data are primarily based on heavily loaded filters.

Equations that relate the production of suspended material in a trickling filter can be developed in a form similar to that used in predicting activated sludge production. The main difference lies in the term used to define the quantity of microorganisms in the system. In long-term studies of trickling filter performance, Merrill (64) assumed that the total mass of microorganisms present in the system was proportional to the media surface area. The resulting equation for volatile solids production was:

$$P_x = Y'(s_r) - K_d'(A_m) \tag{4-7}$$

where:

P_x = net growth of biological solids (VSS), pounds per day or kg per day;

Y' = gross yield coefficient, pound per pound or kg/kg;

k_d' = decay coefficient, day^{-1};

s_r = substrate (for example, BOD_5) removed, pounds per day or kg/day = BOD_5 in minus soluble effluent BOD_5;

A_m = total media surface area in reactor, square feet or sq m.

TABLE 4-7

TRICKLING FILTER SOLIDS PRODUCTION

Plant	Unit solids production[a] Total BOD_5 basis[b]	IT-ES BOD_5 basis[c]	IT-ES COD basis[d]	SS basis[e]	VSS basis[f]	Solids percent volatile	BOD_5 load[g]	Media	Reference
Stockton, California[h]								Plastic, 27 ft^2/ft^3	65
Average of 13 months	0.74	0.67	0.43	1.00	0.94	77	27		
Highest month	1.01 (5/76)	0.92 (5/76, 7/76)	0.60 (7/76)	1.17 (6/76, 1/77)	1.08 (10/76)	86 (8/76, 11/76)	73 (8/76)		
Lowest month	0.49 (1/77)	0.48 (1/77)	0.30 (1/77)	0.61 (3/76)	0.60 (3/77)	64 (3/76, 6/76)	15 (6/76)		
Sacramento, California[h]								Plastic	66
9 noncanning months									
Average	-	-	-	1.01	1.00	78	-		
Highest month	-	-	-	1.09	1.09	83	-		
3 canning months									
Average	-	-	-	1.20	1.24	76	-		
Dallas, Texas	0.42	-	-	-	-	-	-	Rock	67
Dallas, Texas	0.65	-	-	-	-	-	-	Rock	67
Livermore, California	1.10[i]	-	-	1.39	1.51	84	57	Rock 2 to 4 in.	68
San Pablo, California	-	-	-	1.39	-	-	199	Plastic, 29 ft^2/ft^3	37
Seattle, Washington[j]	-	0.8-0.9	-	1.0	-	-	30-250	Plastic, various	64

[a]Solids production includes both waste sludge (clarifier underflow) and clarifier effluent solids.

[b]Pounds volatile suspended solids (VSS) per pound BOD_5 removed (same as kg/kg). BOD_5 removal based on total (suspended plus dissolved) measurements.

[c]Pounds VSS per pound BOD_5 removed. BOD_5 removal based on influent total minus effluent soluble (IT-ES) measurements.

[d]Pounds VSS per pound chemical oxygen demand (COD) removed. COD removal based on influent total minus effluent soluble measurements.

[e]Pounds total suspended solids (SS) produced per pounds SS applied.

[f]Pounds VSS produced per pound VSS applied.

[g]Pounds total BOD_5 applied per day per 1,000 cubic feet of media.

[h]Stockton and Sacramento plants have heavy industrial loads about August to October from fruit and vegetable canneries.

[i]Roughing filter. For BOD_5 basis, BOD_5 removal was computed by $BOD_{5,in}$ minus (0.5 times unsettled $BOD_{5,out}$). 1971 average data.

[j]Pilot studies. SS basis was found to describe data well over a wide range of loadings. Wastewater included some industrial load and recycle liquors from dewatering digested sludge.

The production of trickling filter sludge requiring subsequent sludge handling may be expressed:

$$WTFS = P_x + I_{NV} - E_T \tag{4-8}$$

where:

WTFS = waste trickling filter sludge production, pounds per day or kg/day;

I_{NV} = non-volatile suspended solids fed to the process, pounds per day or kg/day;

E_T = effluent suspended solids, pounds per day or kg/day.

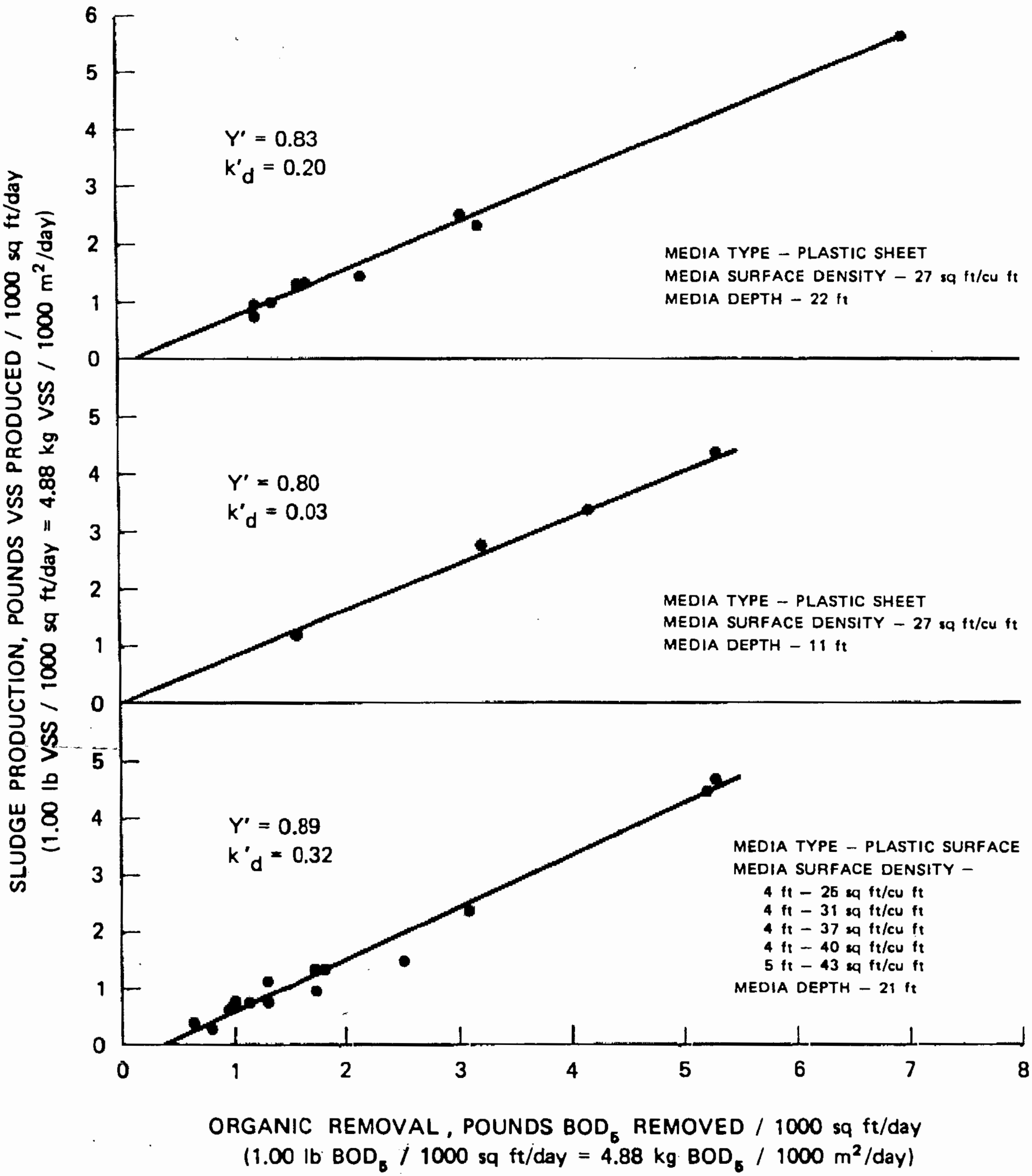
The coefficients Y' and k_d' for Equation 4-7 are obtained for a particular system by computing the slope and intercept of a line of best fit through plotted data points for $\frac{P_x}{A_m}$ vs $\frac{s_r}{A_m}$. VSS production data for three different trickling filter media designs are given on Figure 4-6.

Nitrification in trickling filters causes a synthesis of nitrifying bacteria. As in activated sludge, however, the quantity is small. A value of 25 pounds per million gallons (3 mg/l) has been suggested for design purposes (67). This quantity must be added to the other solids produced by the trickling filter.

It is known that temperature and loading rate affect sludge production: "The quantity of excess sludge produced in a low-rate trickling filter is much lower than that reported for high-rate filters or for the activated sludge process. The lower rate of solids accumulation may be attributable to the grazing activities of protozoa. The activity of the protozoa is reduced considerably at low temperatures (47)." However, there are few data to quantify these variations.

Peak sludge loads are produced by trickling filters. These may be due to variations in influent load, rapid climatic changes, and/or biochemical factors that cause unusually large amounts of biomass to peel off from the media. The term "sloughing" is used by some authorities to include steady state as well as peak solids discharges. Others restrict the term "sloughing" to unusually large discharges. In any case, peak solids loads must be considered. Table 4-8 shows some variations due to both unusual biomass discharges and to variations in influent load. Table 4-9, on the other hand, shows the biomass discharge alone. Each of the three events in Table 4-9 "occurred during periods of light organic loadings (30 to 50 pounds BOD_5 per 1,000 cubic feet per day [0.49 to 0.81 kg/m^3/day]) which had been preceded by periods in which exceptionally heavy organic loadings (215 to 235 pounds BOD_5 per 1,000 cubic feet per day [3.48 to 3.81 kg/m^3/day]) had been applied on a sustained basis (4-14 days)" (64). Table 4-9 shows that effluent solids were much greater than influent solids. This is quite different from average conditions, under which effluent solids were about equal to the influent solids.

In low-rate filters especially, there are seasonal variations in solids production. "Slime tends to accumulate in the trickling filter during winter operation and the filter tends to unload the slime in the spring when the activity of the microorganisms is once again increased" (47).



(1.00 ft = 0.30m)
(1.00 sq ft / cu ft = 3.28 m^2/m^3)

FIGURE 4-6

VSS PRODUCTION DATA FOR THREE TRICKLING MEDIA DESIGNS (64)

TABLE 4-8

DAILY VARIATIONS IN TRICKLING FILTER EFFLUENT, STOCKTON, CALIFORNIA (65)

Period	Number of samples[a]	Average TSS, mg/l	Coefficient of variation[b]	Five percent ratio[c]
March-July 1976	57	144	0.28	1.5
August-September 1976[d]	26	187	0.33	1.6
November 1976 - March 1977	51	149	0.31	1.7

[a]Samples are trickling filter effluent (before sedimentation), total suspended solids, 24-hour refrigerated composites. Flow variations within each sample population were small; that is, ratios in this table represent mass variations as well as concentration variations.

[b]Standard deviation divided by average.

[c]Ratio of individual sample concentration to average concentration that is exceeded by 5 percent of the samples.

[d]Heavy industrial load in August and September from fruit and vegetable canneries.

TABLE 4-9

DESCRIPTION OF SLOUGHING EVENTS (65)

Period	Duration, days	Suspended solids, mg/l		Flow, gpm/sq ft		Applied loading,[c] lb BOD_5/1,000 cu ft/day	Media specific surface, sq ft/cu ft
		Influent	Effluent	Influent[a]	Recycle[b]		
October 22-26, 1976	5	114	256	0.44	2.06	33	27[d]
August 5-6, 1977	2	132	289	0.63	1.56	50	27[d]
July 31-August 5, 1977	6	147	222	0.63	1.56	50	Graded[e]

[a]Influent wastewater flow divided by plan area of filter.

[b]Recycle flow (from trickling filter effluent) divided by plan area of filter.

[c]Based on influent flow.

[d]Plastic sheet media, 22 ft deep.

[e]Plastic sheet media, 22 ft deep; specific surface ranged from 25 sq ft/cu ft at the top of the filter to 43 sq ft/cu ft at the bottom.

1 gpm/sq ft = 2.46 $m^3/hr/m^2$
1 lb BOD_5/1,000 cu ft/day = 0.0162 $kg/m^3/day$

The amount of solids requiring sludge treatment depends on sedimentation performance, which is usually 50 to 90 percent removal of suspended solids. Sedimentation performance is improved by careful design, light loads, tube settlers, and coagulation and flocculation (19,64).

4.3.3.2 Concentration of Trickling Filter Sludge

Trickling filter sludge loadings on the secondary sedimentation tank are typically low--5 to 10 percent of observed solids loads to activated sludge sedimentation tanks. Trickling filter sludge also has better thickening properties than activated sludge. Consequently, trickling filter sludge can be withdrawn at a much higher concentration than waste-activated sludge. Concentration data are summarized in Table 4-10.

TABLE 4-10

CONCENTRATION OF TRICKLING FILTER SLUDGE WITHDRAWN FROM FINAL CLARIFIERS

Type of sludge	Percent dry solids	Comments	Reference
Trickling filter, alone	5 - 10	Depends on solids residence time in trickling filter	69
	7		13
	7	Low-rate trickling filter	70
	3	High-rate trickling filter	70
	3 - 4		71
	4 - 7		2
Trickling filter, combined with raw primary	3 - 6		2,69

The solids flux method for predicting sludge concentration may be used with trickling filter sludge (52). This method requires measurement of initial solids settling velocity versus solids concentration. Such relationships have been reported for at least one trickling filter process (64).

4.3.3.3 Properties - Trickling Filter Sludge

Table 4-11 contains a few analyses of trickling filter sludge properties. The microbial population that inhabits a trickling filter is complex and includes many species of algae, bacteria, fungi, protozoa, worms, snails, and insects. Filter flies and their larvae are often present in large numbers around trickling filters.

4.3.4 Sludge from Rotating Biological Reactors

Rotating biological reactors (RBRs) are used for the same basic purposes as activated sludge and trickling filters: to remove BOD_5 and suspended solids and, where necessary, to nitrify. The RBR process uses a tank in which wastewater, typically primary effluent, contacts plastic media in the shape of large discs. Bacteria grow on the discs. The discs rotate slowly on horizontal shafts; the bacteria are alternately submerged in the wastewater and exposed to air. Excess bacteria slough from the discs into the wastewater. After contacting the bacteria, the wastewater flows to a sedimentation tank, where the excess bacteria and other wastewater solids are removed. These removed solids are RBR sludge. RBR sludge is roughly similar in quantity by dry weight, nutrient content, and other characteristics, to trickling filter sludge.

TABLE 4-11

TRICKLING FILTER SLUDGE COMPOSITION

Property	Value	Comments	Reference
Volatile content, percent of total solids	64 - 86	See Table 4-7	-
Nitrogen, percent of total solids	1.5 - 5	Depends on length of storage of sludge in filter.	69
	2.9		71
	2.0		13
Phosphorus as P_2O_5, percent of total solids	2.8		71
	1.2		13
Fats, percent of total solids	6	Ether soluble.	13
Grease, percent of total solids	0.03	Test slime grown in primary effluent.	72
Specific gravity of individual solid particles	1.52		73
	1.33		2
Bulk specific gravity (wet)	1.02		13
	1.025		2
Color	Grayish brown		13
	Black		64

A small body of published data is available on RBR sludge production rate from full-scale municipal installations. At Peewaukee, Wisconsin, total suspended solids production has been reported to be 0.62 to 0.82 pounds of total suspended solids per pound BOD_5 (0.62 to 0.82 kg TSS/kg) removed. The final sedimentation tank removed 70 to 83 percent of these solids as sludge. The biological sludge alone had a concentration of 1.5 to 5.0 percent solids. Other investigations of municipal and industrial waste applications have concluded that sludge production for the RBR process amounts to 0.4 to 0.5 pound of total suspended solids per pound of BOD_5 (0.4 to 0.5 kg TSS/kg BOD_5) removed (74,75,76).

4.3.5 Coupled Attached-Suspended Growth Sludges

There are several installations of coupled attached and suspended growth processes in the United States. These dual processes are usually installed where nitrification is required or where strong wastes must be treated. The attached growth reactor is a trickling filter or a rotating biological reactor. Its role is to reduce the load on the suspended growth process. The suspended growth process uses an aeration tank and a final clarifier. Flow recirculation is usually practiced around the attached growth reactor. Several reports describe these processes and note that the sludge is similar to activated sludge, both in quantity and in characteristics (5,67,68,77,78). The sludge characterized in Table 4-12 contains some particles of dense solids from the attached growth reactor. These particles may improve the thickening characteristics of the sludge (78).

TABLE 4-12

SLUDGE FROM COMBINED ATTACHED-SUSPENDED GROWTH PROCESSES

Process	Location	Solids production lb TSS produced/ lb BOD_5 removed	Percent volatile	Primary sludge mixed with biological sludge: Percent solids	Primary sludge mixed with biological sludge: Percent volatile
Roughing filter plus nitrifying activated sludge	Livermore, California (68)	0.98	Not stated	3.3	84
Roughing filter plus nitrifying activated sludge	San Pablo, California (37)	1.47	78.2	Not stated	Not stated

4.3.6 Denitrification Sludge

Denitrification is a biological process for the removal of nitrate from wastewater. An electron donor, carbon in primary effluent or methanol, is added to the nitrate-bearing wastewater. Denitrifying bacteria extract energy for growth from the reaction of nitrate with the electron donor:

$$\text{Nitrate + Electron donor (reduced state)} \longrightarrow$$

$$\text{Nitrogen gas + Oxidized electron donor + Energy}$$

Denitrification has been extensively studied, and a few denitrification processes have been built into municipal plants. Denitrifying bacteria can grow either in a suspended growth system similar to activated sludge or in an attached growth system similar to a trickling filter. Sludge production for ordinary nitrified domestic waste is roughly 300 pounds per million gallons (30 mg/l) of wastewater treated (37).

4.4 Chemical Sludges

4.4.1 Introduction

Chemicals are widely used in wastewater treatment to precipitate and remove phosphorus, and in some cases, to improve suspended solids removal. At all such facilities, chemical sludges are formed. A few plants apply chemicals to secondary effluent and

Memorandum

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Date: November 15, 2013

To: Mark Bottin, PE

From: Mark Strahota, PE
Andre Van Niekirk, PE
Jamie Gellner, PE
Paul Pitt, PE

Re: City of Reading
Improvements to the Fritz Island WWTP
Trickling Filter Effluent Evaluation – RK&K Response

Hazen and Sawyer has received the RK&K memo dated November 12, 2013, and we understand the City's desire for both engineering firms to agree on the process parameters to be used for the design. In the November 12th memo, RK&K provides a point-by-point discussion and eventual rejection of Hazen and Sawyer's recommendations in their entirety. They also provide as justification that they are "ultimately responsible for the design," and as such, have expended considerable effort to "right-size" the components of the proposed system. Hazen and Sawyer recognizes RK&K's efforts and technical capability to provide a robust and reliable treatment plant design; this was never in question. However, our intent is to minimize any process risk with a cost-effective design for the benefit of the City.

In the interest of allowing the design process to proceed without further interruption, we will refrain from reiterating all of the recommendations presented in our previous memo. Similarly, we will not dissect RK&K's November 12th memo. Our responsibility on this project is to provide design oversight, which includes ensuring that the City is not only getting the necessary reliability with their treatment plant upgrade, but avoiding a potentially overdesigned facility. With this responsibility in mind, we previously identified several areas where we believed the design to be overly conservative, resulting in additional capital investment. We stand by these statements and recommendations, and are confident that Alternative H-2 as presented in the Act 537 Special Study is a sound design and the best path forward for the City. Accordingly, we are prepared to further substantiate any of our previous work if requested by the City.

As the project team moves forward with the project, we are hopeful that future collaboration will include ideas from both engineers that could improve the design. As an example, in the November 12th memo RK&K dismisses Hazen and Sawyer's potential interim solution of using step feed and anoxic zones to improve performance of the proposed activated sludge system. RK&K provides several reasons for this dismissal, including that it "was not contemplated in the Act 537 Special Study," and it is "inconsistent with the intention to use a five-stage Bardenpho configuration in the future." We disagree with RK&K that step-feed is inconsistent with the use of a five-stage Bardenpho. In fact there are many advantages to a step-feed configuration and anoxic zones, both in operating costs and treatment performance, which would be realized in both the current design and the future BNR configuration.

To demonstrate the benefits of step feed, we modified the latest BioWin model provided by RK&K (*3 Tanks-10.5 deg C All Solids Train Revised Aeration Tank Size for RKK.bwc*) to include the ability to step feed trickling filter effluent to various locations in the activated sludge basins. A schematic of this updated model is presented in Figure 1. *Without changing any of the other parameters in the model developed by RKK* (i.e.

setting aside our previous recommendations), we were able to achieve an effluent NH_3-N concentration of 2.5 mg/L with 6.0 MG of reactor volume and an operating MLSS in the third pass of 4300 mg/L.

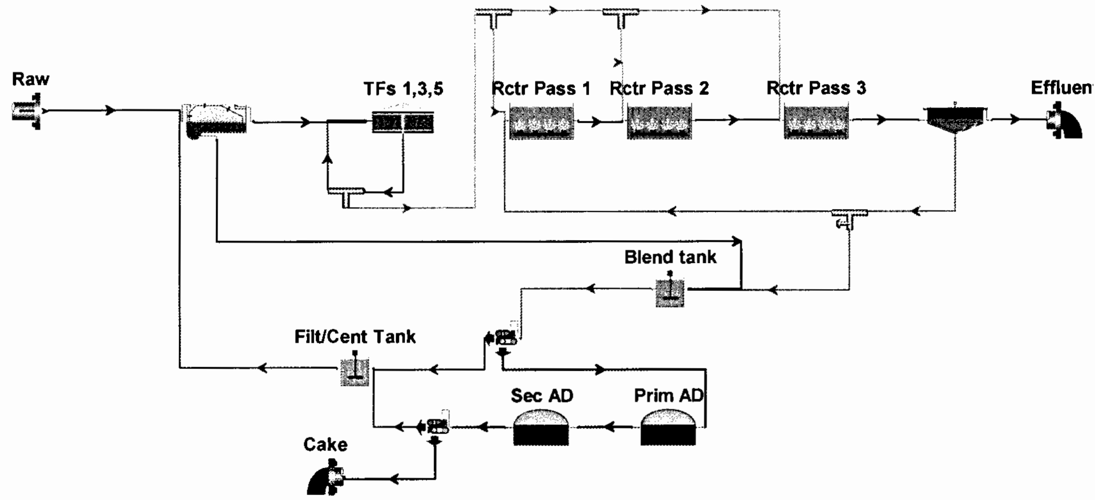

Figure 1. Updated BioWin Model with Step Feed Configuration

The use of step feed in the example shown in Figure 1 has clear treatment benefits, including the ability to control how much treatment is achieved under varying influent conditions, temperature, and permit limits. The ability to route a portion of the flow into downstream zones allows the City to treat to the current permit limits while maintaining the ability to increase performance at a moment's notice. For example, the plant operators can route more flow to downstream zones and still meet permit while saving operational costs related to aeration demand. In addition they could still fully nitrify when needed because there was no loss of nitrifying population while using step feed.

In a five-stage Bardenpho system, the use of step feed allows the influent flow – with soluble BOD – to be routed to downstream anoxic zones for denitrification, thereby minimizing the use of supplemental carbon. This operational cost savings could offset the additional capital cost for adding step feed capability. Similarly, there are operational cost savings associated with using anoxic zones upstream of aerobic zones, even in the current design. We would also point out that the "significant additional capital costs" cited by RK&K to add step feed capability would certainly be less than an additional 1.5 or 3.0 MG of new aerobic reactor volume.

While we recognize that the recommendations for step feed and anoxic zones were not included in the Special Study, that should not preclude Hazen and Sawyer from making recommendations for design improvements at this (still preliminary) stage. Of significance, RKK is responsible for ensuring that the design will accommodate future permit requirements in a cost-effective way. We should also note that RK&K's proposed new snail removal facilities were not contemplated in the Special Study either. The anticipated $5.3 million cost for the snail removal facilities is significant, particularly in consideration that the proposed trickling filter improvements will likely prevent excess snail production in the future. We recommend that the City reserve space for snail removal facilities, but delay installation until after snail production with the new system has been observed.

In our experience the most successful projects often result from superior collaborative efforts. Hazen and Sawyer will continue to ensure that the City receives a reliable, flexible, and cost effective design throughout the project.

A SIMPLE SOLUTION TO BIG SNAIL PROBLEMS - A CASE STUDY AT VSFCD'S RYDER STREET WASTEWATER TREATMENT PLANT

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ABSTRACT

A treatment facility operating on the northern edge of the San Francisco Bay, in Vallejo, California, was experiencing excessive growth of trickling filter snails in the plant's two biotowers. Downstream of the biotowers, the snail shells would settle in the plant's aeration basins and secondary clarifiers and cause major maintenance problems. Periodically the entire aeration basin and clarifier structures were removed from service and manually cleaned to remove the snail shells. As part of a larger plant improvements project, the owner teamed with Carollo Engineers to develop and evaluate solutions to the snail shell problem. Several alternatives were developed, and the most promising alternatives were tested for effective removal or prevention of the snail shell issue.

Pilot testing of an alternative, which included baffles in the aeration basins and the use of grit pumps and classifier systems, proved very effective at snail shell removal. A similar system was designed for permanent installation at the plant, and for a relatively low cost, compared to the excessive manual labor requirements, the snail shell removal system was installed and is currently operating. Initial testing of the system and periodic monitoring of the downstream basins has shown that the custom-engineered snail removal system is very effective at long-term shell removal and disposal.

KEYWORDS

Snails, Snail Shells, Bio-tower, Trickling Filter, Maintenance Improvements

INTRODUCTION

The Vallejo Sanitation and Flood Control District (VSFCD) operates the Ryder Street Wastewater Treatment Plant, with dry weather flows averaging 10.5 mgd, and peak wet weather flows above 60 mgd. The plant has been historically challenged by the growth and subsequent sloughing of snail shells from its two bio-towers, the heart of its treatment process. If allowed to build-up, the shells cause major operational problems in the plant's aeration basins and downstream processes, and removal of the shells has been a difficult and labor-intensive chore.

To address the problem, VSFCD and Carollo Engineers evaluated several alternatives to prevent or reduce growth of the snails, versus alternatives to provide better removal of the shells from the process stream. As a result, the preferred alternative has been implemented, and through an innovative use of existing tankage, the problems with snails have been greatly reduced, without major capital investment.

GOALS AND OBJECTIVES

In order to identify and address the issues caused by snail shells at the plant, VSFCD initiated an evaluation with the following goals and objectives:

1. Characterize and quantify the problems caused by snail shells in the processes downstream of the plant's biotowers.

2. Identify and evaluate alternatives to prevent snail formation, or to provide simple and efficient removal of the shells from the flow stream.

3. Recommend and construct modifications to reduce or eliminate the O&M issues with snails in the aeration basins, clarifiers, and other areas of the plant.

IDENTIFYING THE PROBLEM

The plant's two bio-towers are 105-feet in diameter, and use 24-feet of plastic cross-flow media to treat primary effluent and remove the majority of the soluble BOD and ammonia nitrogen coming to the facility. Unfortunately, several years after startup of the bio-towers, plant staff noticed the presence of snail shells settling in the downstream aeration basins and even floating on the surface of the secondary clarifiers. Periodic draining of the aeration basins and clarifiers revealed huge deposits of the snail shells in those tanks, after relatively short cycles of operation. Figures 1 and 2 depict a typical build-up of snail shells in the plant's aeration tanks, as seen after draining.

Attempts were made to alleviate the snail problem and improve biotower performance by slowing down the trickling filter mechanisms, according to recommendations by Albertson[1].

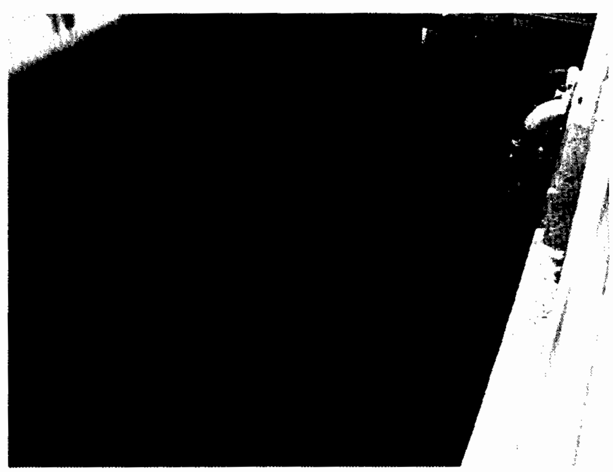


Figure 1 – Snail Shells in Existing Basins

Figure 2 – Pile of Shells at Basin Inlet

Slowing the mechanisms was accomplished by retrofitting the hydraulically-operated mechanisms with new, electrically-driven mechanisms.

The new mechanisms improved flushing within the trickling filter and some aspects of filter operation, but were ineffective at reducing the snail growth. For several years, the plant staff addressed the problem by shutting down and draining the aeration basins on at least a semi-annual basis. Staff then used shovels, buckets and hoses to remove the shells from the basins. One small drain line in each aeration basin was quickly overwhelmed during the cleaning process, by shells clogging the drain and blocking the approach to the drain. Similarly, the secondary clarifiers routinely experienced a build-up of the snail shells in the influent center wells, which required similar periodic draining and manual labor to remove.

An investigation into the layers of plastic bio-tower media revealed that the top four-feet of media contained thicker bio-growth but no snails, while the lower 20-feet contained very thin bio-growth, and an abundance of snails. The snails were thriving on the aerobic conditions in the lower portions of the towers, and large numbers were sloughing off. Due to a specific gravity slightly higher than one, the snails were being pumped by the plant's intermediate pumps into the aeration basins, where the majority settled under the diffusers, while some became air bubble-entrained and were carried on to the secondary clarifiers.

POTENTIAL SOLUTIONS

As part of a larger improvement design project at the plant, Carollo Engineers initiated an evaluation of alternatives to address the problems with snail shells. Several alternatives were developed and compared, including ideas to limit or prevent the growth of the snails, as well as alternatives involving better containment and removal of the shells from the flow stream.

Alternatives to prevent or limit snail formation included ideas to flood the bio-towers with water periodically, or the addition of a chemical dosing station. The primary mechanism with these alternatives included isolating one of the bio-towers on a routine basis, then either flooding or recycling higher levels of ammonia through the process to kill the snails and prevent their growth. Carollo has implemented this process at other treatment facilities in the West, at times with very good success. However, at VSFCD, the original design of the bio-towers did not provide for flooded conditions, and potential issues with the chemical addition made these alternatives non-feasible, compared to alternatives involving more efficient removal of the shells.

When considering alternatives to provide more efficient and complete removal of the shells from the process, the properties of the shells were scrutinized. Although the shells settle in the aeration basin and have similar properties to grit, they are light enough to be pumped by conventional centrifugal pumps, and a small portion become air-entrained and float. Alternatives were considered to provide an intermediate snail removal process to the entire flow stream, similar to a grit removal process, but the existing site was constrained, and the piping re-configurations and pumping requirements were prohibitive.

Additional alternatives to provide for better removal of the shells were focused on improvements to the existing aeration basins. Improving the aeration basin drain system was considered, which would help get the shells back to the head of the plant during the cleaning cycles. However, improving the drain system did not eliminate the manual cleaning cycle or resolve any of the issues in the downstream clarifiers.

CONCLUSIONS AND RECOMMENDATIONS

The alternative with the most long-term advantages included modifications to the front sections of the plant's two aeration basins, to provide a place for the shells to settle and to provide an

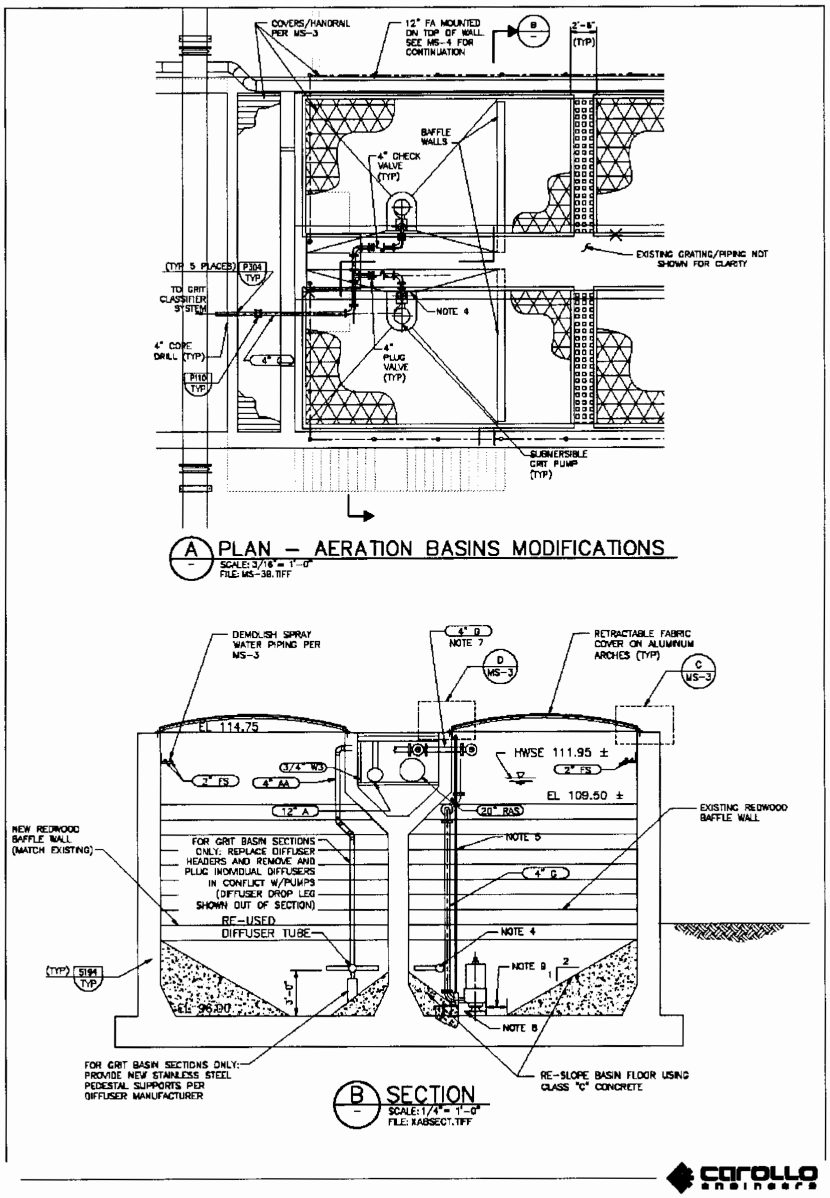


Figure 3 – Modifications to Existing Aeration Basins

automatic mechanism to remove the snails. This was accomplished within the space available in the existing tanks (see Figure 3).

The plan included addition of redwood baffles to confine the snails to the first 20-feet of the rectangular aeration basins. The baffles were added by simply drilling and anchoring stainless steel angle iron to the walls of the basins, and fixing the redwood baffles between the angles. Baffles were added to the entrance sections of the basins to decrease the incoming velocity, and then at the 20-foot mark, to form a compartment to contain the shells. The floor of the 20-foot section was sloped to prevent the shells from piling in the corners and the fine-bubble aeration system was modified to promote settling of the shells and rolling velocity, to push the shells to pumps, for removal from the basins.

The shells are now directed to new submersible grit pumps, set near the center of the 20-foot sections, in the bottom of the aeration basins. The shells are pumped to a new grit cyclone and classifier system, located adjacent to the aeration basins' influent pump station. Overflow from the grit system drains back into the influent pump station and is sent back to the aeration basins, maintaining the suspended solids concentrations in the basins. The grit classifier discharges the shells into bins that are emptied daily, with the plant's screenings and grit, and hauled to a landfill for disposal (see Figures 4 and 5).

Figure 4 – New Grit Cyclone and Classifier

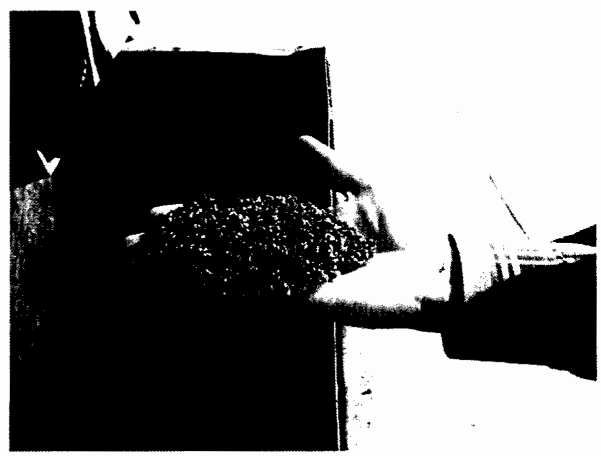
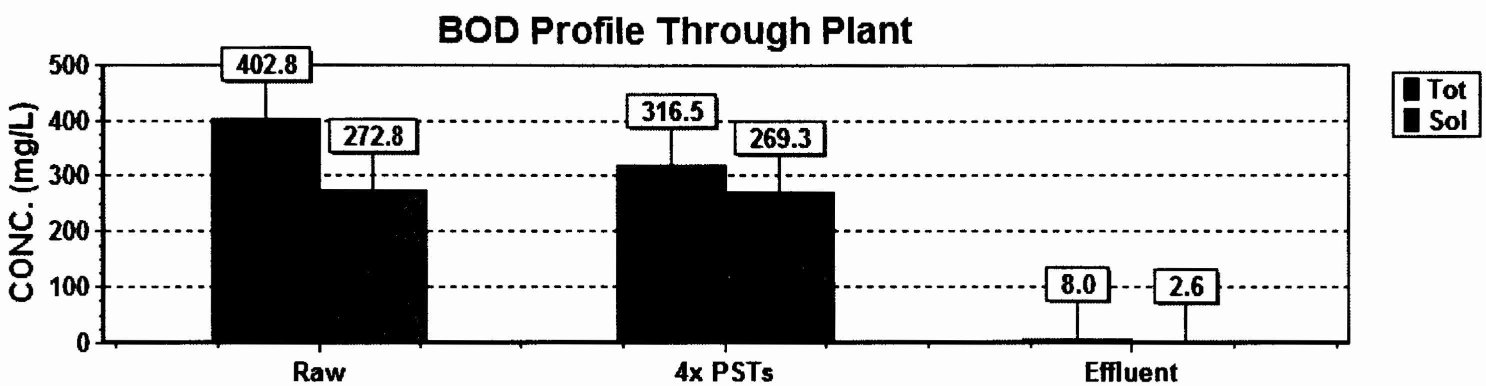


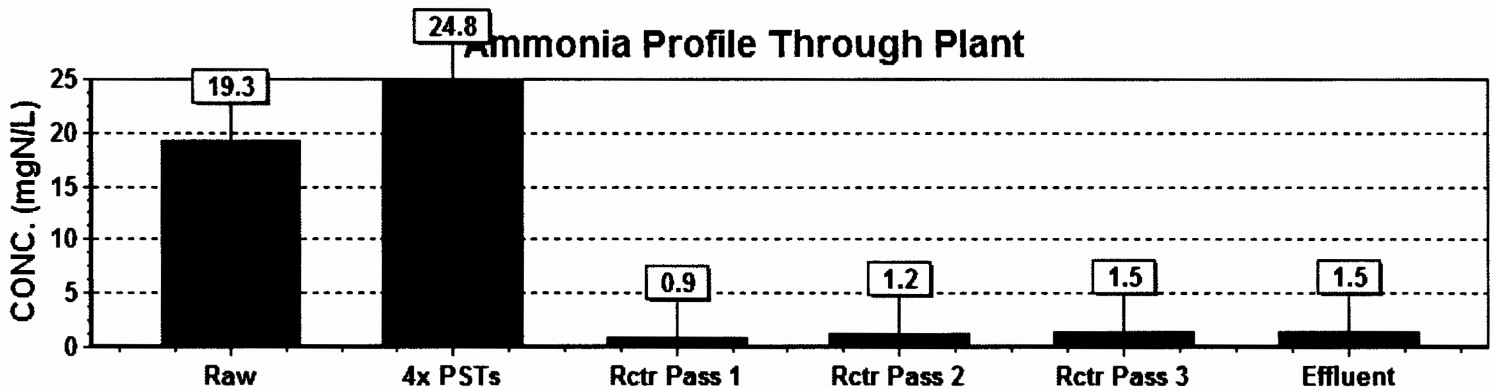
Figure 5 – Classified Snail Shells

The new snail removal system was installed in the Summer of 2005, and during the first few days of operation, removed a large quantity of snail shells from the front of the basins (up to 13 cubic yards per day). Since the startup period, the quantity of shells being removed has stabilized to approximately 2 cubic yards per day, and the plant operators routinely empty the bins to remove the shells from the flow stream. Although during the recent wet weather season, staff has not had the opportunity to take the aeration basins down for inspection, it is expected that very few shells will have settled in the downstream portions of the basins, or in the clarifiers, thereby significantly reducing maintenance efforts and related costs.

REFERENCES

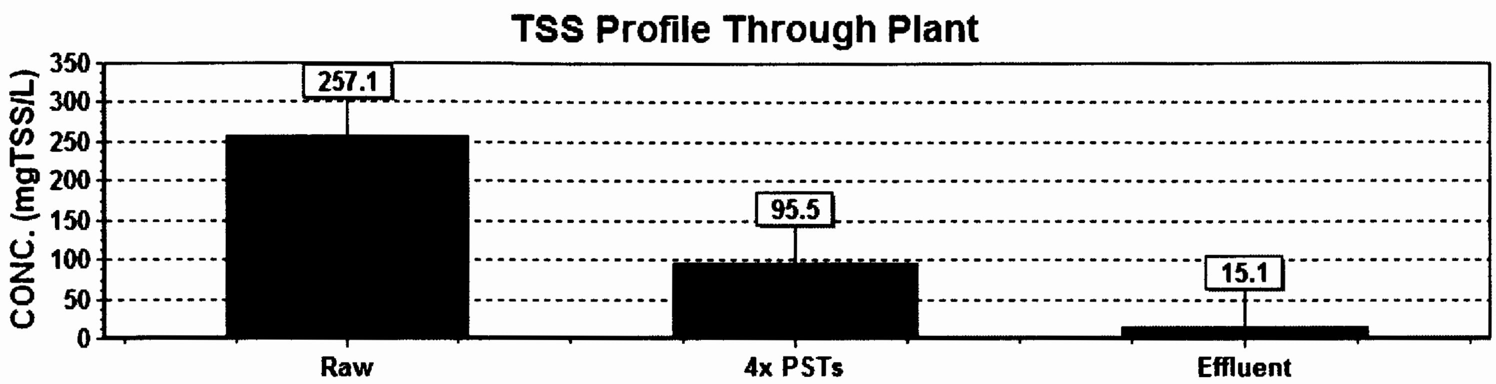
Albertson, O.E., "Slow Down That Trickling Filter!". *WPCF Operations Forum*, January 1989

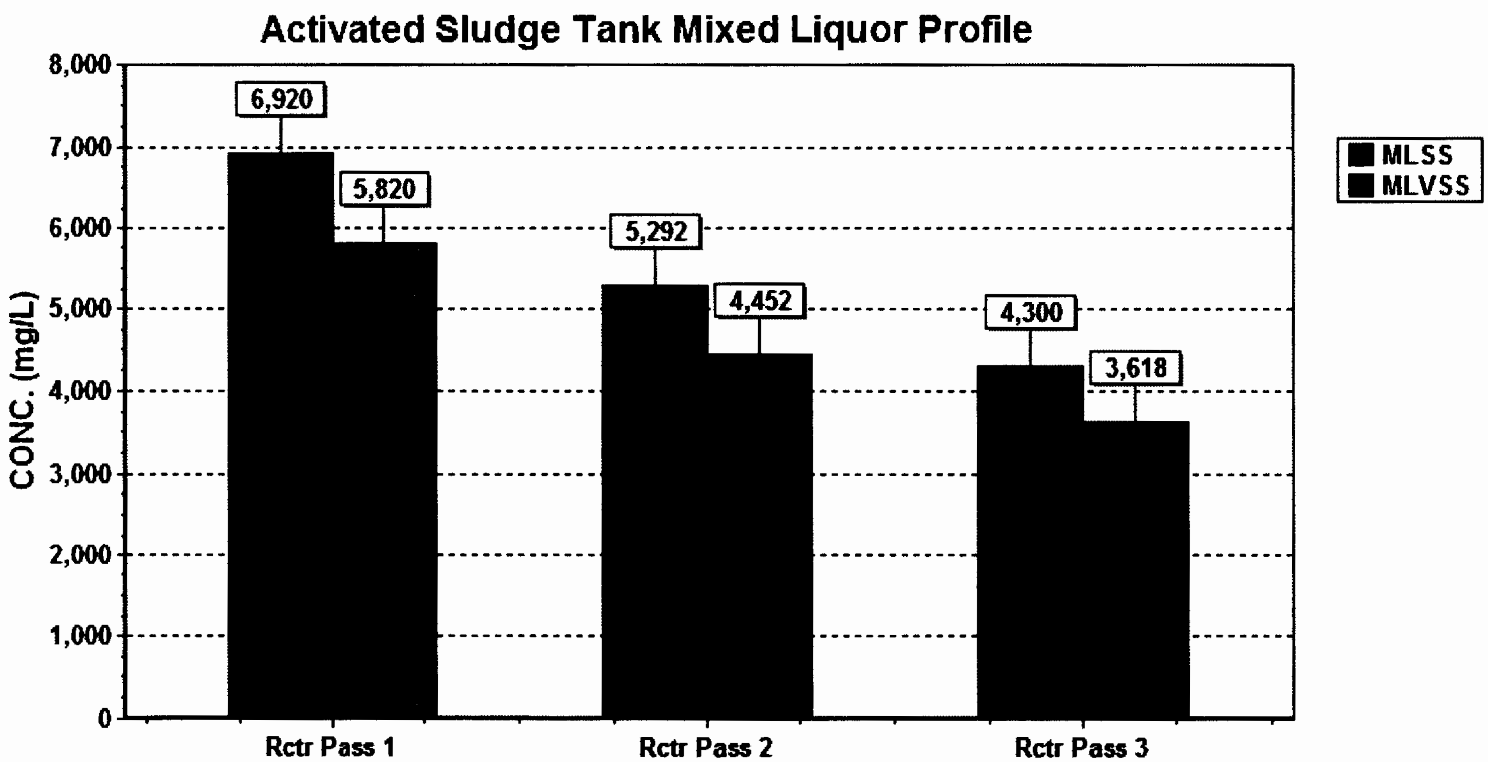




Model Run: AS-1R Initial Conditions

Step-feed; 7.5 MG reactor volume; minimum design temperature 12.2 degree C; 15 day SRT





Model Run: AS-1R Initial Conditions

Step-feed; 7.5 MG reactor volume; minimum design temperature 12.2 degree C; 15 day SRT

Model Run: AS-1R Initial Conditions

Step-feed; 7.5 MG reactor volume; minimum design temperature 12.2 degree C; 15 day SRT

Model Output

Element name	Rctr Pass 1	Rctr Pass 2	Rctr Pass 3	Effluent	
Flow	21.97	28.92	35.86	20.49	mgd
Volatile suspended solids	5820.4	4451.52	3618.43	12.67	mg/l
Total suspended solids	6919.86	5291.95	4300.32	15.06	mg/l
Total COD	8464.9	6483.81	5278.13	59.13	mg/l
Filtered COD	39.75	40.26	40.79	40.79	mg/l
Total N	555.58	429.49	352.29	21.36	mg/l
Total Kjeldahl Nitrogen	538.13	412.33	335.68	4.76	mg/l
Filtered TKN	3	3.28	3.6	3.6	mg/l
Ammonia N	0.95	1.22	1.53	1.53	mg/l
Nitrate N	17.35	17.04	16.46	16.46	mg/l
Total P	173.81	134.09	109.76	5.57	mg/l
Soluble PO4-P	5.37	5.33	5.21	5.21	mg/l
Total Carbonaceous BOD	2475.4	1894.97	1544.67	8.02	mg/l
Filtered Carbonaceous BOD	1.88	2.24	2.62	2.62	mg/l
Volume	2.5	2.5	2.5	0	MG
Temperature	12.2	12.2	12.2	12.2	degree C

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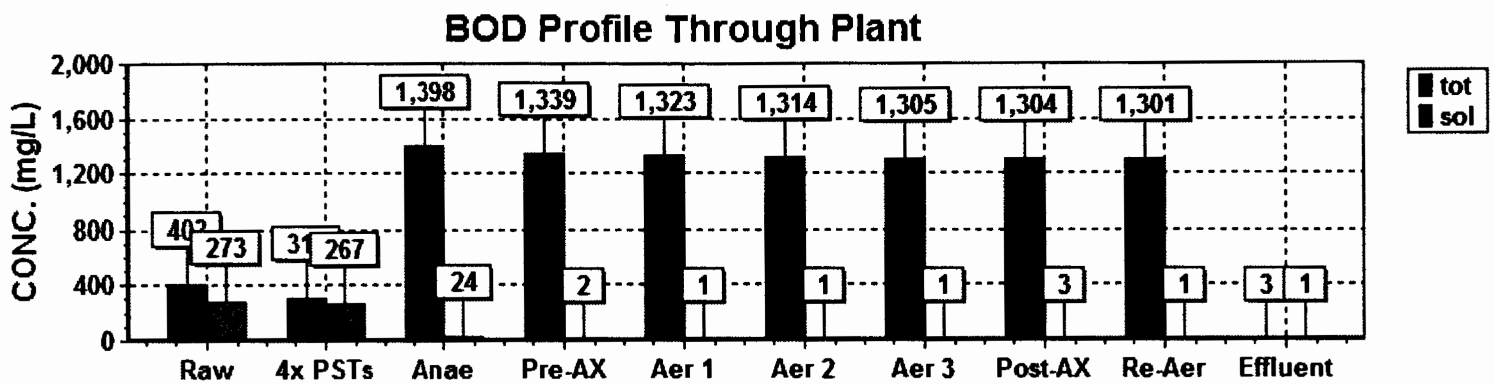
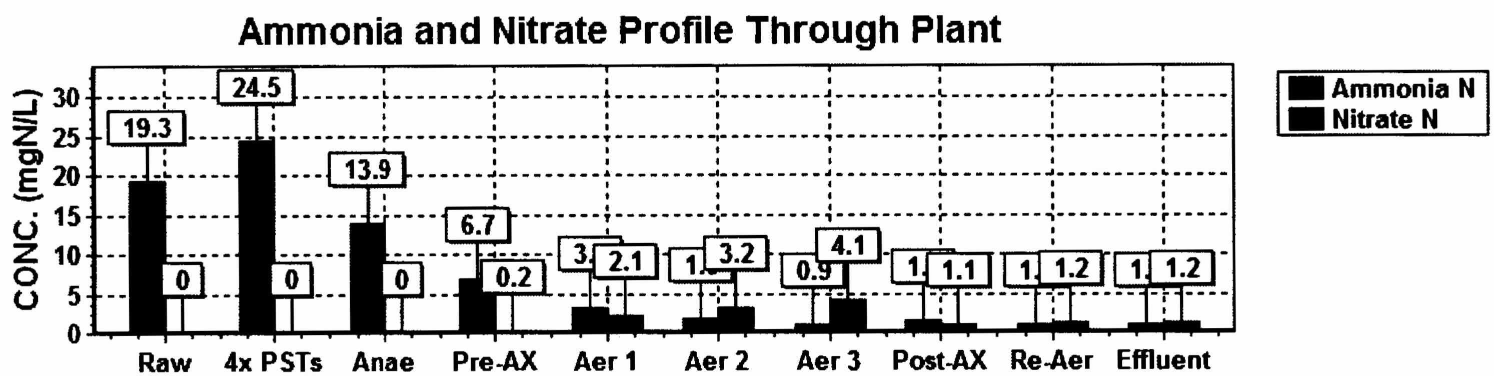
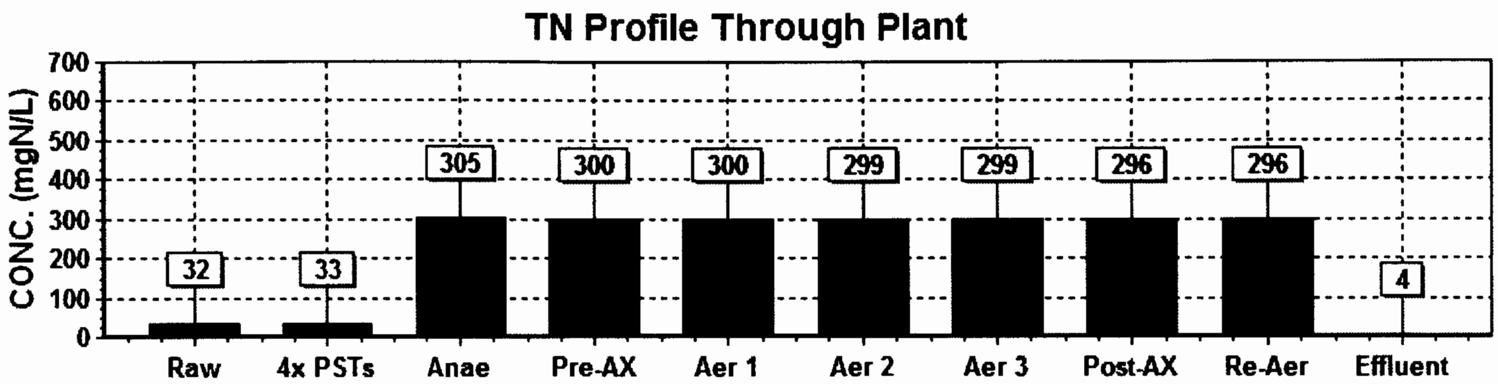
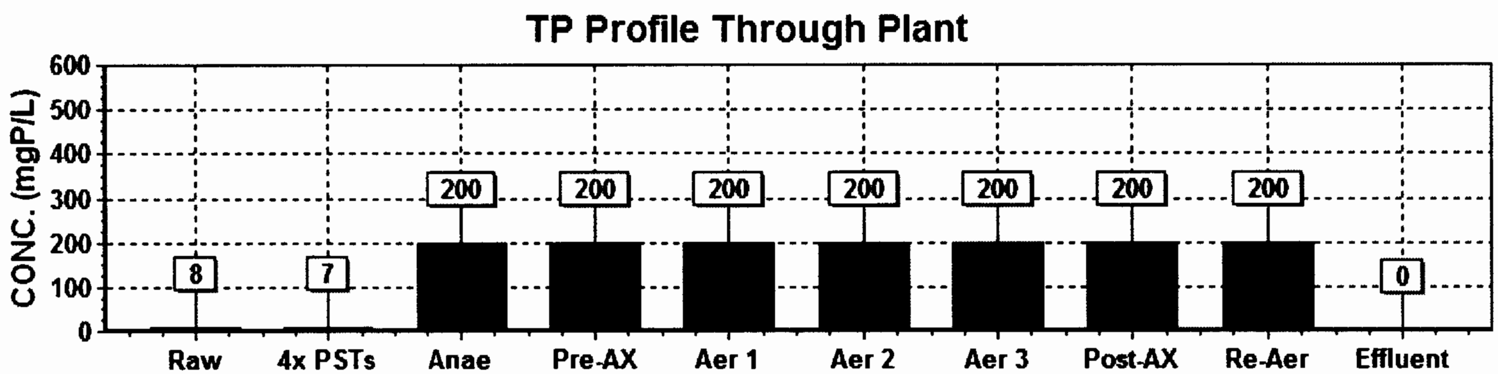


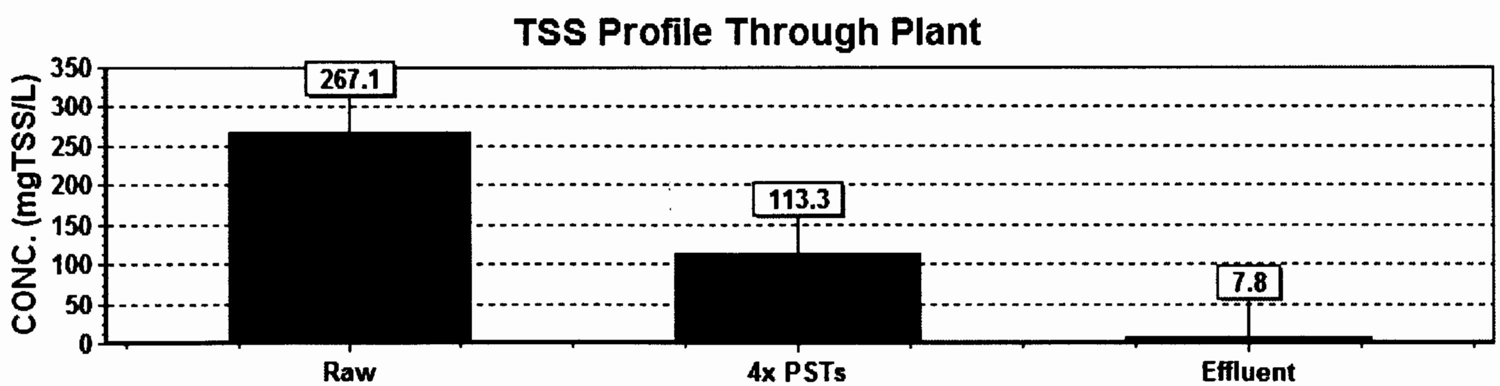


Model Run: AS-1R Future BNR Conditions

Plug-flow; 15 MG reactor volume; minimum design temperature 12.2 degree C

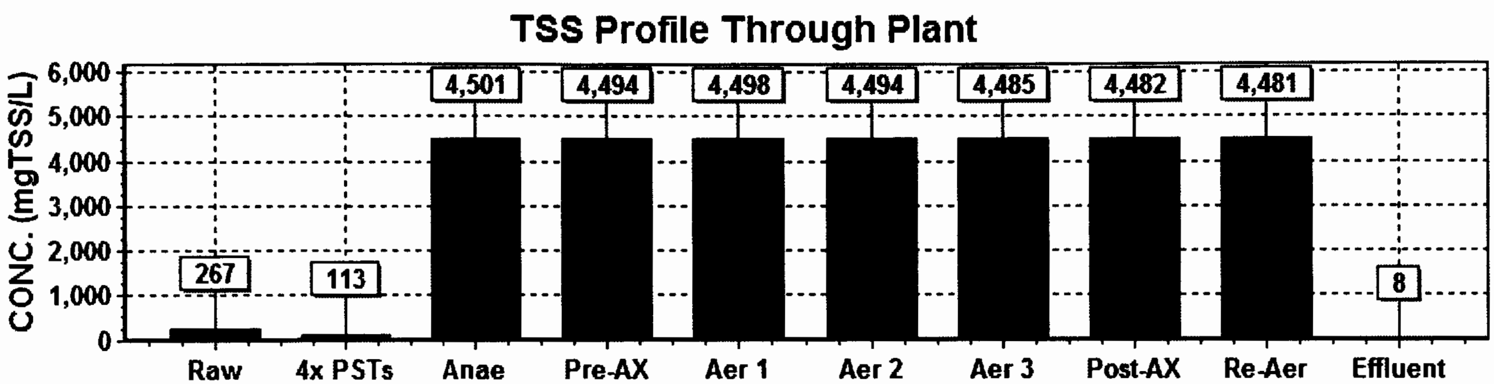


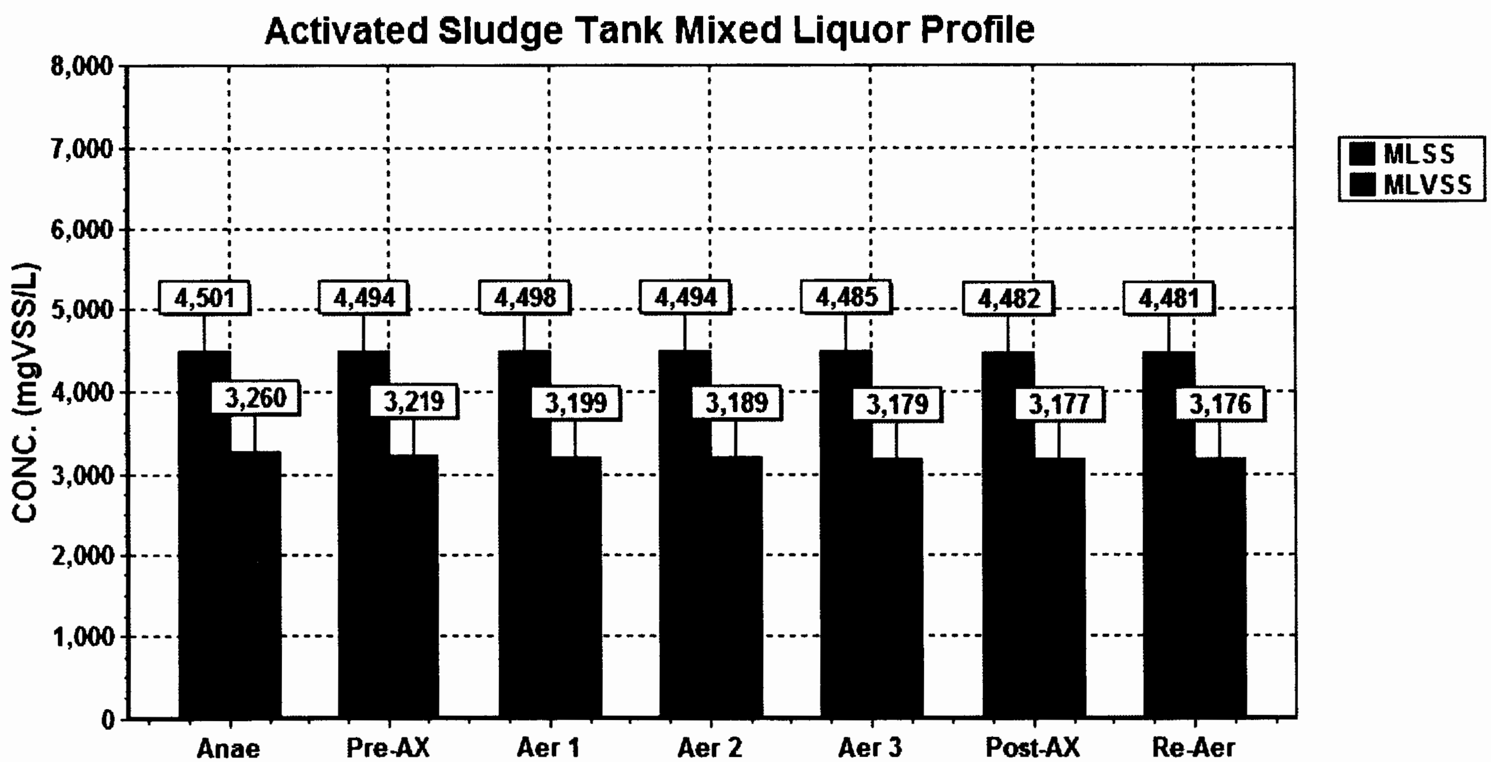




Model Run: AS-1R Future BNR Conditions

Plug-flow; 15 MG reactor volume; minimum design temperature 12.2 degree C





Model Run: AS-1R Future BNR Conditions

Plug-flow; 15 MG reactor volume; minimum design temperature 12.2 degree C

Model Run: AS-1R Future BNR
Conditions

Plug flow; 15 MG reactor volume; minimum design temperature 12.2 degree C;

Model Output

Element name	**Aer 1**	**Aer 2**	**Aer 3**	**Anae**	**Post-AX**	**Pre-AX**	**Pre-AX Sw**	**Re-Aer**	**Effluent**	
Flow	92.24	92.24	92.24	40.99	40.99	92.24	92.24	40.99	20.49	mgd
Volatile suspended solids	3199.11	3188.72	3179.48	3260.46	3176.71	3218.55	3210.86	3175.55	5.53	mg/l
Total suspended solids	4497.72	4493.65	4485.25	4501.3	4482.06	4494.28	4496.55	4481.24	7.81	mg/l
Total COD	4676.6	4661.7	4648.78	4808.47	4648.24	4712.4	4695.01	4643.93	52.92	mg/l
Filtered COD	44.67	44.24	44.24	91.37	47.61	53.49	46.76	44.91	44.91	mg/l
Total N	299.59	299.49	299.41	305.06	296.27	299.79	299.72	296.25	4.46	mg/l
Total Kjeldahl Nitrogen	297.27	296.08	295.17	305.06	295.17	299.54	298.65	294.96	3.17	mg/l
Filtered TKN	5.05	3.69	2.87	15.74	2.9	8.29	6.91	2.66	2.66	mg/l
Ammonia N	3.17	1.76	0.92	13.92	1.41	6.73	5.16	1.01	1.01	mg/l
Nitrate N	2.08	3.21	4.11	0	1.06	0.23	0.88	1.21	1.21	mg/l
Total P	199.94	199.94	199.94	199.94	199.94	199.94	199.94	199.94	0.39	mg/l
Soluble PO4-P	2.18	0.21	0.03	20.59	0.13	9.52	6.31	0.04	0.04	mg/l
Total Carbonaceous BOD	1322.61	1313.63	1305.44	1397.75	1304.29	1339.16	1332.56	1301.26	3.21	mg/l
Filtered Carbonaceous BOD	1.09	0.93	0.85	23.65	2.88	1.77	1.37	0.95	0.95	mg/l
Volume	2.77	2.77	2.77	1.35	1.73	1.67	1.67	0.27	0	MG
Temperature	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	12.2	degree C

H-2R vs. AS-1R Cost Comparison

RK&K- 11/27/2013

Item No.	Item	A	B	C	D
		Vortex Snail Removal Option		Chamber Snail Removal Option	
		H-2R	AS-1R	H-2R	AS-1R
	Construction Costs				
1	TF Distribution Structure	$1,874,000	$0	$1,874,000	$0
2	Trickling filter, includes:	$13,675,000	$0	$13,675,000	$0
	TF Demolition				
	TF Media replacement (Brentwood)				
	TF Rotary distributor replacement (Ovivo)				
	TF Influent pipe - 48" (2 units)				
	TF Influent pipe - 54" (1 unit)				
	TF Flume enlargement (all 3 units)				
	TF effluent sluice gate (all 3 units)				
	48" TF Effluent pipe (TF#5 to TF #3)				
	54" TF Effluent pipe (TF #3 to TF #1)				
	72" TF Effluent pipe (downstream of TF#1)				
	Structural repairs to walls				
3a	Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000	$0		
3b	Snail removal - chamber system - vac removal			$2,500,000	$0
4	Intermediate/recycle PS (Add in cost spreadsheet)	$10,388,000	$0	$10,388,000	$0
5	4 -1.5 MG Reactors step feed	$15,755,000	$0	$15,755,000	$0
6	5 - 1.5 MG Reactors step feed	$0	$19,375,000	$0	$19,375,000
7	72" reactor influent	$0	$400,000	$0	$400,000
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000
9	**Comparative Construction Cost**	$48,027,000	$23,118,000	$44,192,000	$23,118,000
	Operation Costs				
10	PW aeration electrical cost - see below	$7,707,458	$13,668,136	$7,707,458	$13,668,136
11	PW pump forward flow electrical cost - see below	$881,980	$0	$881,980	$0
12	PW pump TF recycle flow electrical cost - see below	$1,841,043	$0	$1,841,043	$0
13	PW snail removal operation cost (no disposal)	$850,319	$0	$143,361	$0
14	**Present Worth of Operation**	$11,280,799	$13,668,136	$10,573,841	$13,668,136
15	**Total Comparative Present Worth (Construction and Annual Electrical)**	$59,307,799	$36,786,136	$54,765,841	$36,786,136

Evolution of H-2R vs. AS-1R Cost Comparison

Step 1 - Developed construction estimate for H-2R

Item	H-2R
TF Distribution Structure	$1,874,000
Trickling filter, includes: TF Demolition TF Media replacement (Brentwood) TF Rotary distributor replacement (Ovivo) TF Influent pipe - 48" (2 units) TF Influent pipe - 54" (1 unit) TF Flume enlargement (all 3 units) TF effluent sluice gate (all 3 units) 48" TF Effluent pipe (TF#5 to TF #3) 54" TF Effluent pipe (TF #3 to TF #1) 72" TF Effluent pipe (downstream of TF#1) Structural repairs to walls	$13,675,000
Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000
Intermediate/recycle PS (Add in cost spreadsheet)	$10,388,000
4 -1.5 MG Reactors step feed	$15,755,000
Construction Cost (Partial)	**$48,027,000**

Cost per reactor approx. $3.9 million

Evolution of H-2R vs. AS-1R Cost Comparison

Step 2 - Developed comparative construction estimate for AS-1

Item	H-2R	AS-1R
Construction Costs		
TF Distribution Structure	$1,874,000	$0
Trickling filter	$13,675,000	$0
Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000	$0
Intermediate/recycle PS (Add in cost spreadsheet)	$10,388,000	$0
4 -1.5 MG Reactors step feed	$15,755,000	$0
5 - 1.5 MG Reactors step feed	$0	$19,375,000
72" reactor influent	$0	$400,000
Additional blowers & enlarged blower building	$0	$3,343,000
Comparative Construction Cost	**$48,027,000**	**$23,118,000**

Evolution of H-2R vs. AS-1R Cost Comparison

Step 3 - Developed comparative PW estimate

	H-2R	AS-1R
Comparative Construction Cost	**$48,027,000**	**$23,118,000**
Operation Costs		
PW aeration electrical cost - see below	$7,707,458	$13,668,136
PW pump forward flow electrical cost - see below	$881,980	$0
PW pump TF recycle flow electrical cost - see below	$1,841,043	$0
PW snail removal operation cost (no disposal)	$850,319	$0
Present Worth of Operation	**$11,280,799**	**$13,668,136**
Total Comparative Present Worth (Construction and Annual Electrical)	**$59,307,799**	**$36,786,136**

Comparative PW Estimate – Electric Costs

PW Costs for aeration		
Blower HP (From blower calcs)	1005	1,782
Blower kW	748	1,327
Annual blower kwh	6,556,637	11,627,310
Elect- $/kwh	0.079	0.079
Annual elect cost	$517,974	$918,558
PW annual elect cost	$7,707,458	$13,668,136

PW Costs to pump forward flow	
Flow, mgd	20.5
Flow, gpm	14227
Head, ft (From KN curves in Liq TM appendix)	24
Efficiency	0.75
Power, hp	115.0
Power, kw	86
Annual pump kw	750,289
Elect - $/kwh	0.079
Annual elect cost	$59,273
PW annual elect cost	**$881,980**

Comparative PW Estimate – Electric Costs

PW Costs to pump TF Recycle flow	
Total flow to TF, mgd	60
Forward flow, mgd	20.5
Pumped recycle flow,mgd	39.5
Flow, gpm	27413
Head, ft (From KN curves in Liq TM appendix)	26
Efficiency	0.75
Power, hp	240.0
Power, kw	179
Annual pump kw	1,566,152
Elect - $/kwh	0.079
Annual elect cost	$123,726
PW annual elect cost	**$1,841,043**

Comparison of Connected Large Equipment Loads

	HP for H-2R	HP for AS-1R
Aeration blowers - 5 @ 500 hp	2,500	
Aeration blowers 7 @ 500 hp		3,500
Forward flow pumps - 4 duty @ 170hp	680	
Forward flow pump - 1 standby @ 170 hp	170	
TF Recycle pump - 3 @ 125 hp	375	
Total	3,725	3,500

No difference in electric service needed for H-2R and AS-1R

Comparative PW Estimate – Process Aeration Details

W/ TRICKLING FILTERS. STEP FEED

WP = wire power consumption, hp	**1005**
q_s = standardized volumetric airflow rate, scfm	16385
q_a = actual airflow rate, acfm	18828
AOR = actual oxygen requirement, lb/d	42200
SOTR = standard oxygen transfer rate, lb/d	108552
SOTE = standard oxygen transfer efficiency, function of depth, flux, and density, %	**26.5%**
Ta = blower inlet air temperature, degrees F	51.5
e = combined blower/motor efficiency	**0.63**
Pb = field atmosphere pressure, psia	14.58
Pd = blower discharge pressure, psig	11.31
α = (process water $K_l a$ of a new diffuser)/(clean water $K_l a$ of a new diffuser)	0.50
F = (process water $K_L a$ of a diffuser after a given time in service)/($K_L a$ of a new diffuser in the same process water) = fouling factor	0.95
Θ = 1.024	1.02
T = Process water temperature, C	**10.50**
$\Theta^{T-20} = K_l a/K_l a_{20}$	0.80
Ω = Pressure correction for C* ~ Pb/Ps	0.99
Ps = standard atmospheric pressure (14.7 psia)	14.70
τ = Temperature correction for $C^* = C^*/C^*_{20} = C^*_s/C^*_{s20}$	1.23
β = (process water C*)/(clean water C*)	0.98
C^*_{20} = steady state DO saturation concentration attained at infinite time for a given diffuser at 20 C and 1 atm, mg/l	11.47
C = Process water DO concentration, mg/l	**2.00**

ALL ACTIVATED/ STEP FEED

750.5 kW

WP = wire power consumption, hp	**1782**
q_s = standardized volumetric airflow rate, scfm	29057
q_a = actual airflow rate, acfm	33388
AOR = actual oxygen requirement, lb/d	70600
SOTR = standard oxygen transfer rate, lb/d	181607
SOTE = standard oxygen transfer efficiency, function of depth, flux, and density, %	**25.0%**
Ta = blower inlet air temperature, degrees F	51.5
e = combined blower/motor efficiency	**0.63**
Pb = field atmosphere pressure, psia	14.58
Pd = blower discharge pressure, psig	11.31
α = (process water $K_l a$ of a new diffuser)/(clean water $K_l a$ of a new diffuser)	0.50
F = (process water $K_L a$ of a diffuser after a given time in service)/($K_L a$ of a new diffuser in the same process water) = fouling factor	0.95
Θ = 1.024	1.02
T = Process water temperature, C	10.50
$\Theta^{T-20} = K_l a/K_l a_{20}$	0.80
Ω = Pressure correction for C* ~ Pb/Ps	0.99
Ps = standard atmospheric pressure (14.7 psia)	14.70
τ = Temperature correction for $C^* = C^*/C^*_{20} = C^*_s/C^*_{s20}$	1.23
β = (process water C*)/(clean water C*)	0.98
C^*_{20} = steady state DO saturation concentration attained at infinite time for a given diffuser at 20 C and 1 atm, mg/l	11.47
C = Process water DO concentration, mg/l	**2.00**

Notes:

AOR values provided by BioWin modeling for average flow/load conditions

BioWin modeling scfm values: 16,300 scfm for w/ TFs; 28,800 scfm for all activated/step feed

Blower/motor efficiency estimated

Air temperature based on annual average temperature

Process water temperature selected to match modeling run process temperatures

Comment #2 – Cost for TF Dist Structure & Intermediate/Recycle PS

- **Comment/Response** – Provide details /See below

No.	Description	Notes	Quantity	Unit	Material/Equipment Unit Price	Material/Equipment Total Price	DERIVED COSTS Installation Unit Price	Installation Total Price	Material + Install Total	Unit Price	Total Price	TOTAL DERIVED+ BID COSTS
	TRICKLING FILTER DIST. BOX											
	Excavation		1213	CY						$50	$60,667	
	Gravel Below Slab		70	CY						$50	$3,481	
	Backfill		308	CY						$50	$15,407	
	Slab concrete		152	CY						$800	$121,956	
	Elevated Slab		30	CY						$1,200	$36,000	
	Wall concrete		486	CY						$800	$388,634	
	Flowable fill		0	CY						$350	$0	
	Grating - Solid Plate		1880	SF	$20	$37,600	$4	$7,520				
	Stairs		42	unit						$150	$6,274	
	Handrail		174	LF	$15	$2,610	$5	$870				
	Weir plate		12	each	$1,500	$18,000	$1,125	$13,500				
	Stop Logs (90" long)		12	each	$14,338	$172,056	$2,868	$34,411				
	Davit crane		1	LS	$6,000	$6,000	$1,200	$1,200				
	Sluice Gate (72")		1	each	$41,800	$41,800	$8,360	$8,360				
	Sluice Gate (42")		4	each	$21,900	$87,600	$4,380	$17,520				
	Sluice Gate (54")		0	each	$32,050	$0	$6,410	$0				
	Sluice Gate (48")		1	each	$26,000	$26,000	$5,200	$5,200				
	Mixer		2	each	$6,500	$13,000	$1,300	$2,600				
	Bypass Flow Submersible Pumps		2	each	$20,000	$40,000	$4,000	$8,000				
	VFDs		2	each	$8,000	$16,000	$1,600	$3,200				
	Subtotals 1					$460,666		$102,381				
	Taxes - 6% material, 25% labor					$27,640		$25,595				
	Subtotals 2					$488,306		$127,977	$616,282			
	Overhead & profit - 20%								$123,256			
	Subtotals 3								$739,539		$632,419	
	Subtotal 4											$1,371,958
	Contingency			30%								$411,588
	TOTAL	a										**$1,783,546**

Comment #2 – Cost for TF Dist Structure & Intermediate/Recycle PS

- Comment/Response – Provide details / See below

					DERIVED COSTS							TOTAL
					Material/Equipment		Installation		Material +			DERIVED+
No.	Description	Notes	Quantity	Unit	Unit Price	Total Price	Unit Price	Total Price	Install Total	Unit Price	Total Price	BID COSTS
	INTERMEDIATE/RECYCLE PUMP STATION											
	Structural											
	Excavation		8638	CY						$50	$431,912	
	Backfill		2488	CY						$50	$124,396	
	Gravel Below Slab		207	CY						$50	$10,353	
	Slab concrete		449	CY						$800	$359,585	
	Elevated Slab		179	CY						$1,200	$214,333	
	Wall concrete		1585	CY						$800	$1,267,674	
	Grating		1361	SF	$20	$27,225	$4	$5,445				
	Walls - Type 1		1560	sf						$20	$31,200	
	Stairs		96	unit						$150	$14,400	
	Handrail		60	LF	$15	$900	$5	$300				
	Bollards		6	each	$400	$2,400	$80	$480				
	Roofing		600	SF						$35	$21,000	
	Architectural											
	Doors		3	each	$800	$2,400	$160	$480				
	Double Doors		1	each	$1,200	$1,200	$240	$240				
	Access Hatch		1	each	$4,000	$4,000	$800	$800				
	Process Mechanical											
	6-Ton Crane System		1	each	$60,000	$60,000	$12,000	$12,000				
	36" Sluice Gate		4	each	$15,000	$60,000	$3,000	$12,000				
	Forward Flow Submersible Pumps		5	each	$155,000	$775,000	$31,000	$155,000				
	Recycle Submersible Pumps		3	each	$135,000	$405,000	$27,000	$81,000				
	Sump pumps		2	each	$2,000	$4,000	$400	$800				
	Mechanical											
	HVAC		1	LS							$65,000	

Comment #2 – Cost for TF Dist Structure & Intermediate/Recycle PS

- Comment/Response – Provide details / See below

Piping and Valves										
10" Check Valve	6	each	$2,300	$13,800	$460	$2,760				
10" Plug Valve	2	each	$2,500	$5,000	$500	$1,000				
10" Flex Coupling	2	each	$900	$1,800	$180	$360				
20" ELL	8	each	$4,000	$32,000	$800	$6,400				
20" x 24" Check Valve	8	each	$11,000	$88,000	$2,200	$17,600				
24" Gate Valve	8	each	$19,000	$152,000	$3,800	$30,400				
24" Flex Coupling	8	each	$2,400	$19,200	$480	$3,840				
24" x 30" Reducer	8	each	$12,000	$96,000	$2,400	$19,200				
30" x 48" Tee	9	each	$21,000	$189,000	$4,200	$37,800				
48" Knife Gate Valve	2	each	$26,000	$52,000	$5,200	$10,400				
20" Wall Pipe	8	each	$6,000	$48,000	$1,200	$9,600				
48" Wall Pipe	2	each	$25,000	$50,000	$5,000	$10,000				
36" Wall Pipe	5	each	$19,000	$95,000	$3,800	$19,000				
4-8" Piping	50	lf						$75	$3,750	
10" Piping	106	lf						$100	$10,600	
20" Piping	344	lf						$200	$68,800	
24" Piping	50	lf							$0	
48" Piping	50	lf						$500	$25,000	
Piping Support System	1	LS							$125,000	
Electrical										
Lighting/Power/Control Wiring	1	LS							$350,000	
FF VFDs	5	each	$60,000	$300,000	$12,000	$60,000				
TF VFDs	3	each	$50,000	$150,000	$10,000	$30,000				
Subtotals 1				$2,633,925		$526,905				
Taxes - 6% material, 25% labor				$158,036		$131,726				
Subtotals 2				$2,791,961		$658,631	$3,450,592			
Overhead & profit - 20%							$690,118			
Subtotals 3							$4,140,710		$3,123,004	
Subtotal 4										$7,263,714
Contingency		30%								$2,179,114
TOTAL	a									**$9,442,828**

Comment #3 – Cost for Aeration Basins

- Comment/Response – Provide details / See below

					DERIVED COSTS							TOTAL
					Material/Equipment		Installation		Material +			DERIVED+
No.	Description	Notes	Quantity	Unit	Unit Price	Total Price	Unit Price	Total Price	Install Total	Unit Price	Total Price	BID COSTS
	4 REACTORS											
	Excavation		27000	CY						$50	$1,349,985	
	Gravel Below Slab		1416	CY						$50	$70,778	
	Backfill		2850	CY						$50	$142,516	
	Slab concrete		2894	CY						$800	$2,315,378	
	Elevated Slab		384	CY						$1,200	$461,333	
	Wall concrete		3657	CY						$800	$2,925,742	
	Stairs		120	unit						$150	$18,000	
	Handrail		3460	LF	$15	$51,900	$5	$17,300				
	6" Butterfly Valve		20	each	$2,400	$48,000	$480	$9,600				
	24" Butterfly Valve		4	each	$10,000	$40,000	$2,000	$8,000				
	step feed slide gates		20	each	$21,900	$438,000	$4,380	$87,600				
	4-6" Flowmeter		20	each	$2,000	$40,000	$400	$8,000				
	54" sluice gates		12	each	$32,050	$384,600	$6,410	$76,920				

Comment #3 – Cost for Aeration Basins

- <u>Comment/Response</u> – Provide details / See below

4-8" Piping	1400	lf						$75	$105,000	
12-16" Piping	1200	lf						$100	$120,000	
8" Piping (SS Air - reaeration zone)	425	lf						$200	$85,000	
24" Piping (SS Air)	1200	lf						$300	$360,000	
36" Piping (contact stab RAS)	130	lf						$250	$32,500	
30" Piping (step feed)	1200	lf						$225	$270,000	
Air diffusers	1	LS	$433,333	$433,333	$86,667	$86,667				
Air header support frames	120	each						$2,000	$240,000	
Dewatering pumps	4	each	$15,000	$60,000	$3,000	$12,000				
Step feed weir	160	lf						$50	$8,000	
Launders	12	each						$5,000	$60,000	
Bollards	8	each	$400	$3,200	$80	$640				
Yard hydrants	8	each	$1,000	$8,000	$300	$2,400				
6" Mud valve	20	each	$2,300	$46,000	$460	$9,200				
Subtotals 1				$1,553,033		$318,327				
Taxes - 6% material, 25% labor				$93,182		$79,582				
Subtotals 2				$1,646,215		$397,908	$2,044,124			
Overhead & profit - 20%							$408,825			
Subtotals 3							$2,452,948		$8,564,232	
Subtotal 4										$11,017,181
Contingency		30%								$3,305,154
TOTAL	a									**$14,322,335**

Comment #4 – Cost for Trickling Filter Rehabilitation

- **Comment/Response** – Provide details / See below

No.	Description	Notes	Quantity	Unit	Material/Equipment Unit Price	Material/Equipment Total Price	Installation Unit Price	Installation Total Price	Material + Install Total	Unit Price	Total Price	TOTAL DERIVED+ BID COSTS
	DERIVED COSTS											
	TRICKLING FILTERS											
	Remove existing media / underdrains etc		23532	CY						$50	$1,176,600	
	Remove 36" influent pipe		318	LF						$50	$15,900	
	Rebuild center flume		3	LS						$50,000	$150,000	
	48" influent pipe		250	LF						$400	$100,000	
	54" influent pipe		550							$500	$275,000	
	New media, underdrains, grating		1	LS	$4,197,600	$4,197,600	$629,640	$629,640		$50	$50	
	Rotary distributor, motorized		1	LS	$1,150,000	$1,150,000	$172,500	$172,500		$75	$75	
	Effluent sluice gate		3	each	$26,000	$78,000	$5,200	$15,600				
	48" effluent pipe		510	lf						$400	$204,000	
	54" effluent pipe		220	lf						$500	$110,000	
	72" effluent pipe		150	lf						$700	$105,000	
	Wall repair		3	each						$50,000	$150,000	
	Subtotals 1					$5,425,600		$817,740				
	Taxes - 6% material, 25% labor					$325,536		$204,435				
	Subtotals 2					$5,751,136		$1,022,175	$6,773,311			
	Overhead & profit - 20%								$1,354,662			
	Subtotals 3								$8,127,973		$2,286,625	
	Subtotal 4											$10,414,598
	Contingency			30%								$3,124,379
	TOTAL	a										**$13,538,978**

$5.3m vendor cost for media and RD

Sensitivity of Cost Comparison to Comment #2

Sensitivity Analysis to Comments # 2, 3, 4 & 7
RK&K - 12/5/2013

		A	B	C	D	
		Vortex Snail Removal Option		Chamber Snail Removal Option		Comment
Item No.	Item	H-2R	AS-1R	H-2R	AS-1R	
	Construction Costs					
1	TF Distribution Structure	$800,000	$0	$800,000	$0	#2 - More than twice as costly Was $1,874,000
2	Trickling filter	$13,675,000	$0	$13,675,000	$0	
3a	Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000	$0			
3b	Snail removal - chamber system - vac removal			$2,500,000	$0	
4	Intermediate/recycle PS (Add in cost spreadsheet)	$5,000,000	$0	$5,000,000	$0	#2 - More than twice as costly Was $10,388,000
5	4 -1.5 MG Reactors step feed	$15,755,000	$0	$15,755,000	$0	
6	5 - 1.5 MG Reactors step feed	$0	$19,375,000	$0	$19,375,000	
7	72" reactor influent	$0	$400,000	$0	$400,000	
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000	
9	**Updated Comparative Construction Cost based on Comment #2**	**$41,565,000**	**$23,118,000**	**$37,730,000**	**$23,118,000**	
	Original Comparative Construction Cost	**$48,027,000**	**$23,118,000**	**$44,192,000**	**$23,118,000**	
	Operation Costs					
10	PW aeration electrical cost - see below	$7,707,458	$13,668,136	$7,707,458	$13,668,136	
11	PW pump forward flow electrical cost - see below	$881,980	$0	$881,980	$0	
12	PW pump TF recycle flow electrical cost - see below	$1,841,043	$0	$1,841,043	$0	
13	PW snail removal operation cost (no disposal)	$850,319	$0	$143,361	$0	
14	**Present Worth of Operation**	**$11,280,799**	**$13,668,136**	**$10,573,841**	**$13,668,136**	
15	**Updated Comparative Present Worth based on Comment #2**	**$52,845,799**	**$36,786,136**	**$48,303,841**	**$36,786,136**	
	Original Comparative Present Worth	**$59,307,799**	**$36,786,136**	**$54,765,841**	**$36,786,136**	

Sensitivity of Cost Comparison to Comments #2 & 3

Sensitivity Analysis to Comments # 2, 3, 4 & 7
RK&K - 12/5/2013

		A	B	C	D	
		Vortex Snail Removal Option		Chamber Snail Removal Option		Comment
Item No.	Item	H-2R	AS-1R	H-2R	AS-1R	
	Construction Costs					
1	TF Distribution Structure	$800,000	$0	$800,000	$0	#2 - More than twice as costly Was $1,874,000
2	Trickling filter	$13,675,000	$0	$13,675,000	$0	
3a	Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000	$0			
3b	Snail removal - chamber system - vac removal			$2,500,000	$0	
4	Intermediate/recycle PS (Add in cost spreadsheet)	$5,000,000	$0	$5,000,000	$0	#2 - More than twice as costly Was $10,388,000
5	4 -1.5 MG Reactors step feed	$10,000,000	$0	$10,000,000	$0	#3 - Very high Was $15,755,000
6	S - 1.5 MG Reactors step feed	$0	$13,000,000	$0	$13,000,000	#3 - Very high Was $19,375,000
7	72" reactor influent	$0	$400,000	$0	$400,000	
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000	
9	**Updated Comparative Construction Cost based on Comments #2 & 3**	**$35,810,000**	**$16,743,000**	**$31,975,000**	**$16,743,000**	
	Original Comparative Construction Cost	**$48,027,000**	**$23,118,000**	**$44,192,000**	**$23,118,000**	
	Operation Costs					
10	PW aeration electrical cost - see below	$7,707,458	$13,668,136	$7,707,458	$13,668,136	
11	PW pump forward flow electrical cost - see below	$881,980	$0	$881,980	$0	
12	PW pump TF recycle flow electrical cost - see below	$1,841,043	$0	$1,841,043	$0	
13	PW snail removal operation cost (no disposal)	$850,319	$0	$143,361	$0	
14	**Present Worth of Operation**	**$11,280,799**	**$13,668,136**	**$10,573,841**	**$13,668,136**	
15	**Updated Comparative Present Worth based on Comments #2 & 3**	**$47,090,799**	**$30,411,136**	**$42,548,841**	**$30,411,136**	
	Original Comparative Present Worth	**$59,307,799**	**$36,786,136**	**$54,765,841**	**$36,786,136**	

Sensitivity of Cost Comparison to Comments #2, 3, & 4

Sensitivity Analysis to Comments # 2, 3, 4 & 7
RK&K - 12/5/2013

		A	B	C	D	
		Vortex Snail Removal Option		Chamber Snail Removal Option		Comment
Item No.	Item	H-2R	AS-1R	H-2R	AS-1R	
	Construction Costs					
1	TF Distribution Structure	$800,000	$0	$800,000	$0	#2 - More than twice as costly Was $1,874,000
2	Trickling filter	$9,000,000	$0	$9,000,000	$0	#4 - Almost twice as high Was $13,675,000
3a	Snail removal - vortex system & concentrator/clarifier bldg	$6,335,000	$0			
3b	Snail removal - chamber system - vac removal			$2,500,000	$0	
4	Intermediate/recycle PS (Add in cost spreadsheet)	$5,000,000	$0	$5,000,000	$0	#2 - More than twice as costly Was $10,388,000
5	4 -1.5 MG Reactors step feed	$10,000,000	$0	$10,000,000	$0	#3 - Very high Was $15,755,000
6	5 - 1.5 MG Reactors step feed	$0	$13,000,000	$0	$13,000,000	#3 - Very high Was $19,375,000
7	72" reactor influent	$0	$400,000	$0	$400,000	
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000	
9	Updated Comparative Construction Cost based on Comments #2, 3 & 4	$31,135,000	$16,743,000	$27,300,000	$16,743,000	
	Original Comparative Construction Cost	**$48,027,000**	**$23,118,000**	**$44,192,000**	**$23,118,000**	
	Operation Costs					
10	PW aeration electrical cost - see below	$7,707,458	$13,668,136	$7,707,458	$13,668,136	
11	PW pump forward flow electrical cost - see below	$881,980	$0	$881,980	$0	
12	PW pump TF recycle flow electrical cost - see below	$1,841,043	$0	$1,841,043	$0	
13	PW snail removal operation cost (no disposal)	$850,319	$0	$143,361	$0	
14	**Present Worth of Operation**	**$11,280,799**	**$13,668,136**	**$10,573,841**	**$13,668,136**	
15	Total Comparative Present Worth based on Comments #2, 3 & 4	$42,415,799	$30,411,136	$37,873,841	$30,411,136	
	Original Comparative Present Worth	**$59,307,799**	**$36,786,136**	**$54,765,841**	**$36,786,136**	

Sensitivity of Cost Comparison to Comments #2, 3, 4 & 7

Sensitivity Analysis to Comments # 2, 3, 4 & 7
RK&K - 12/5/2013

		A	B	C	D	
		Vortex Snail Removal Option		**Chamber Snail Removal Option**		**Comment**
Item No.	**Item**	**H-2R**	**AS-1R**	**H-2R**	**AS-1R**	
	Construction Costs					
1	TF Distribution Structure	$800,000	$0	$800,000	$0	**#2 - More than twice as costly** Was $1,874,000
2	Trickling filter	$9,000,000	$0	$9,000,000	$0	**#4 - Almost twice as high** Was $13,675,000
3a	Snail removal - vortex system & concentrator/clarifier bldg	$0	$0			**#9 - Questioned need for it** Was $6,335,000
3b	Snail removal - chamber system - vac removal			$0	$0	**#9 - Questioned need for it** Was $2,500,000
4	Intermediate/recycle PS (Add in cost spreadsheet)	$5,000,000	$0	$5,000,000	$0	**#2 - More than twice as costly** Was $10,388,000
5	4 -1.5 MG Reactors step feed	$10,000,000	$0	$10,000,000	$0	**#3 - Very high** Was $15,755,000
6	5 - 1.5 MG Reactors step feed	$0	$13,000,000	$0	$13,000,000	**#3 - Very high** Was $19,375,000
7	72" reactor influent	$0	$400,000	$0	$400,000	
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000	
9	Updated Comparative Construction Cost based on Comments #2, 3, 4 & 9	**$24,800,000**	**$16,743,000**	**$24,800,000**	**$16,743,000**	
	Original Comparative Construction Cost	**$48,027,000**	**$23,118,000**	**$44,192,000**	**$23,118,000**	
	Operation Costs					
10	PW aeration electrical cost - see below	$7,707,458	$13,668,136	$7,707,458	$13,668,136	
11	PW pump forward flow electrical cost - see below	$881,980	$0	$881,980	$0	
12	PW pump TF recycle flow electrical cost - see below	$1,841,043	$0	$1,841,043	$0	
13	PW snail removal operation cost (no disposal)	$0	$0	$0	$0	**#9 - Questioned need for it**
14	**Present Worth of Operation**	**$10,430,480**	**$13,668,136**	**$10,430,480**	**$13,668,136**	
15	Total Comparative Present Worth based on Comments #2, 3, 4 & 9	**$35,230,480**	**$30,411,136**	**$35,230,480**	**$30,411,136**	
	Original Comparative Present Worth	**$59,307,799**	**$36,786,136**	**$54,765,841**	**$36,786,136**	

Sensitivity Analysis to Comments # 2, 3, 4 & 7 and higher electrical costs

		A	B	C	D	
		Vortex Snail Removal Option		**Chamber Snail Removal Option**		**Comment**
Item No.	**Item**	**H-2R**	**AS-1R**	**H-2R**	**AS-1R**	
	Construction Costs					
1	TF Distribution Structure	$800,000	$0	$800,000	$0	**#2 - More than twice as costly** Was $1,874,000
2	Trickling filter	$9,000,000	$0	$9,000,000	$0	**#4 - Almost twice as high** Was $13,675,000
3a	Snail removal - vortex system & concentrator/clarifier bldg	$0	$0			**#9 - Questioned need for it** Was $6,335,000
3b	Snail removal - chamber system - vac removal			$0	$0	**#9 - Questioned need for it** Was $2,500,000
4	Intermediate/recycle PS (Add in cost spreadsheet)	$5,000,000	$0	$5,000,000	$0	**#2 - More than twice as costly** Was $10,388,000
5	4 -1.5 MG Reactors step feed	$10,000,000	$0	$10,000,000	$0	**#3 - Very high** Was $15,755,000
6	5 - 1.5 MG Reactors step feed	$0	$13,000,000	$0	$13,000,000	**#3 - Very high** Was $19,375,000
7	72" reactor influent	$0	$400,000	$0	$400,000	
8	Additional blowers & enlarged blower building	$0	$3,343,000	$0	$3,343,000	
9	**Updated Comparative Construction Cost based on Comments #2, 3, 4 & 9**	**$24,800,000**	**$16,743,000**	**$24,800,000**	**$16,743,000**	
	Original Comparative Construction Cost	**$48,027,000**	**$23,118,000**	**$44,192,000**	**$23,118,000**	
	Operation Costs					
10	PW aeration electrical cost - see below	$10,731,904	$19,031,582	$10,731,904	$19,031,582	**Based on $0.11/kWh**
11	PW pump forward flow electrical cost - see below	$1,228,073	$0	$1,228,073	$0	**Based on $0.11/kWh**
12	PW pump TF recycle flow electrical cost - see below	$2,563,477	$0	$2,563,477	$0	**Based on $0.11/kWh**
13	PW snail removal operation cost (no disposal)	$0	$0	$0	$0	**#9 - Questioned need for it**
14	**Present Worth of Operation**	**$14,523,454**	**$19,031,582**	**$14,523,454**	**$19,031,582**	
15	**Total Comparative Present Worth based on Comments #2, 3, 4 & 9**	**$39,323,454**	**$35,774,582**	**$39,323,454**	**$35,774,582**	
	Original Comparative Present Worth	**$59,307,799**	**$36,786,136**	**$54,765,841**	**$36,786,136**	

PW Costs for aeration		
Blower HP (From blower calcs)	1005	1,782
Blower kW	748	1,327
Annual blower kwh	6,556,637	11,627,310
Elect- $/kwh	0.11	0.11
Annual elect cost	$721,230	$1,279,004
PW annual elect cost	$10,731,904	$19,031,582

PW Costs to pump forward flow	
Flow, mgd	20.5
Flow, gpm	14227
Head, ft (From KN curves in Liq TM appendix)	24
Efficiency	0.75
Power, hp	115.0
Power, kw	86
Annual pump kw	750,289
Elect - $/kwh	0.11
Annual elect cost	$82,532
PW annual elect cost	**$1,228,073**

PW Costs to pump TF Recycle flow	
Total flow to TF, mgd	60
Forward flow, mgd	20.5
Pumped recycle flow,mgd	39.5
Flow, gpm	27413
Head, ft (From KN curves in Liq TM appendix)	26
Efficiency	0.75
Power, hp	240.0
Power, kw	179
Annual pump kw	1,566,152
Elect - $/kwh	0.11
Annual elect cost	$172,277
PW annual elect cost	**$2,563,477**

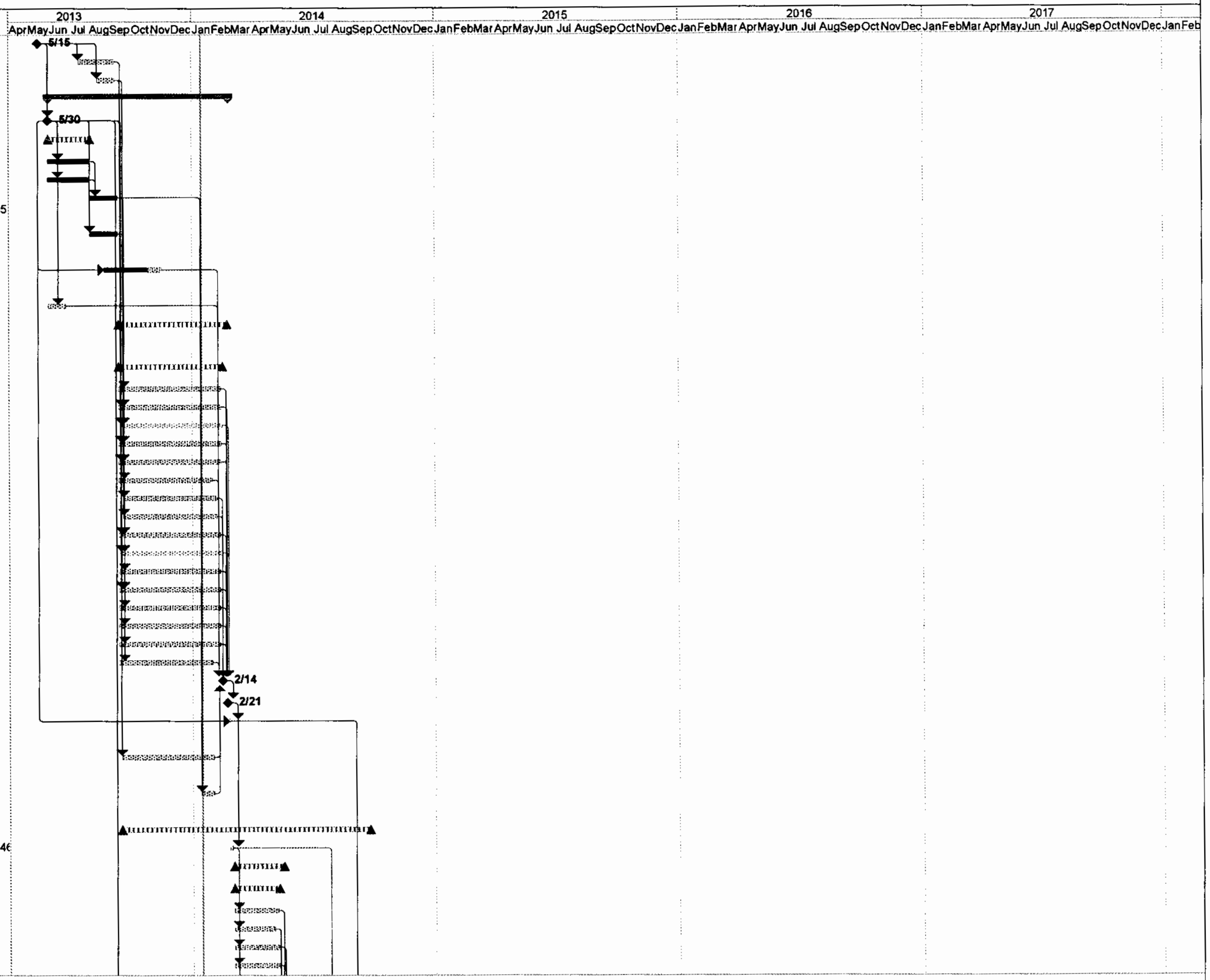
Comparison of Connected Large Equipment Loads

	HP for H-2R	**HP for AS-1R**
Aeration blowers - 5 @ 500 hp	2,500	
Aeration blowers 7 @ 500 hp		3,500
Forward flow pumps - 4 duty @ 170hp	680	
Forward flow pump - 1 standby @ 170 hp	170	
TF Recycle pump - 3 @ 125 hp	375	
Total	3,725	3,500

No difference in electric service needed for H-2R and AS-1R

IMPROVEMENTS TO THE FRITZ ISLAND WWTP

ID	Task Name	Predecessors	Successors
1	***Notice to Proceed***		5,2,3
2	***Task 1D: Site Surveys***	1	23
3	***Task 1E: Geotechnical Investigation***	1	16,17,18,19,21,22,24,26
4	***TASK 2: PRELIMINARY DESIGN***		
5	**Task 2A: Process Kick-off Meeting**	1	8,11SS,10,7,33SS,128,34,12
6	**Task 2B: Development of BioWin Model**		
7	Pilot Study	5	9
8	Model Development	5	9
9	**Task 2C: Liquid Process Technical Memorandum**	8,7	15,16,17,18,19,20,21FS+5 days,22FS+5 days,23,28,29,35
10	**Task 2D: Solids Process Technical Memorandum**	5	23,24,25,26,27,28,29,30
11	**Task 2E: Existing Scrubber System Evaluation**	5SS	31
12	**Task 2F: Oxygen System Evaluation**	5	31
13	**Task 2G: Basis of Design Report / 30% Design**		
14	**Preliminary Plans and Specifications**		
15	Primary Clarifier Modifications	9	31
16	Distribution Structures	9,3	31
17	Activated Sludge Reactor	9,3	31
18	Secondary Clarifiers	9,3	31
19	RAS/WAS Pumping Station	9,3	31
20	CCT and Post-Aeration	9	31
21	Outfall	9FS+5 days,3	31
22	Blower Building	9FS+5 days,3	31
23	Site Improvements	9,10,2	31
24	Solids Handling Facility	10,3	31
25	Primary Digester Rehab	10	31
26	Secondary Digesters	10,3	31
27	CHP System	10	31
28	Yard Piping	9,10	31
29	Building Refurb	9,10	31
30	T&M Coordination	10	31
31	**Submit 30% Design**	15,16,17,18,19,20,21,22,:	32FS+5 days
32	BODR Review Meeting	31FS+5 days	37,33
33	**Task 2H: Equipment Review, Vendor Preferences, and Site Tours**	5SS,32	108,78
34	**Task 2I: Scope for SCADA and Integration Services**	5	31
35	**Task 2K: Supplemental Report for Act 537 Special Study**	9	31
36	***TASK 3: DETAILED DESIGN***		
37	Task 1B: Value Engineering Session	32	129,82,40,49,41,42,43,44,45,4(
38	**Task 3A: 60% Design Liquid**		
39	**Plans and Specifications**		
40	Primary Clarifier Modifications	37	50
41	Distribution Structures	37	50
42	Activated Sludge Reactor	37	50
43	Secondary Clarifiers	37	50

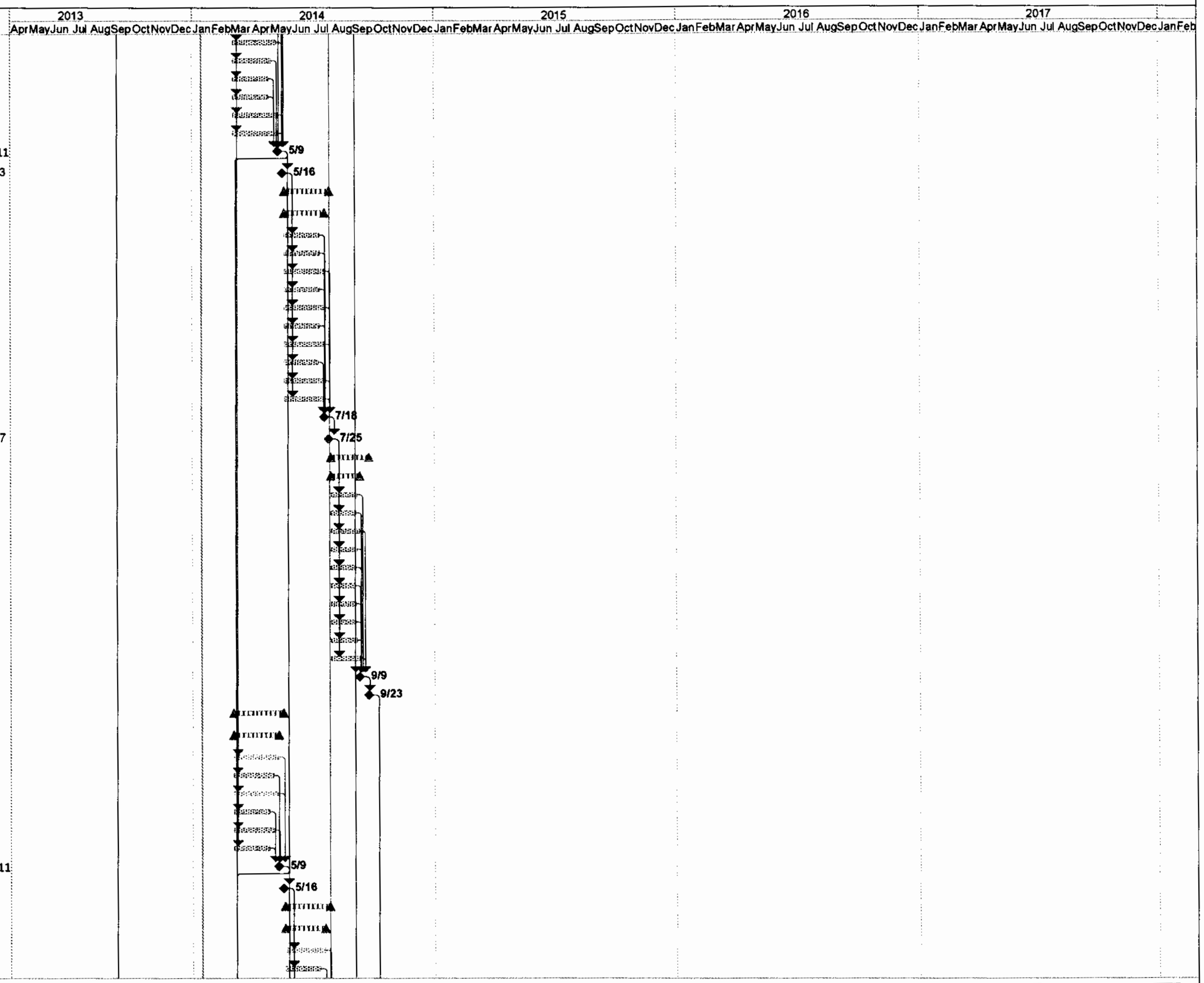


CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP

Task		Project Summary		Inactive Task		Duration-only		Finish-only	
Split		External Tasks		Inactive Milestone		Manual Summary Rollup		Critical	
Milestone		External Milestone		Inactive Summary		Manual Summary		Critical Split	
Summary		Inactive Task		Manual Task		Start-only		Progress	
								Deadline	

IMPROVEMENTS TO THE FRITZ ISLAND WWTP

ID	Task Name	Predecessors	Successors
44	RAS/WAS Pumping Station	37	50
45	Secondary Clarifiers	37	50
46	CCT and Post-Aeration	37	50
47	Outfall	37	50
48	Blower Building	37	50
49	Site Improvements	37	50
50	**Submit 60% Design - Liquid**	49,40,41,42,43,44,45,46,4	51FS+5 days,112FS-30 days,11
51	**Design Review Meeting - Liquid**	50FS+5 days	55,54,56,57,58,59,60,61,62,63
52	**Task 3B: 90% Design Liquid**		
53	**Plans and Specifications**		
54	Primary Clarifier Modifications	51	64
55	Distribution Structures	51	64
56	Activated Sludge Reactor	51	64
57	Secondary Clarifiers	51	64
58	RAS/WAS Pumping Station	51	64
59	Secondary Clarifiers	51	64
60	CCT and Post-Aeration	51	64
61	Outfall	51	64
62	Blower Building	51	64
63	Site Improvements	51	64
64	**Submit 90% Design - Liquid**	63,54,55,56,57,58,59,60,6	65FS+5 days
65	**Design Review Meeting - Liquid**	64FS+5 days	68,69,70,71,72,73,74,75,76,77
66	**Task 3C: 100% Design Liquid**		
67	**Plans and Specifications**		
68	Primary Clarifier Modifications	65	78
69	Distribution Structures	65	78
70	Activated Sludge Reactor	65	78
71	Secondary Clarifiers	65	78
72	RAS/WAS Pumping Station	65	78
73	Secondary Clarifiers	65	78
74	CCT and Post-Aeration	65	78
75	Outfall	65	78
76	Blower Building	65	78
77	Site Improvements	65	78
78	**Submit 100% Design - Liquid**	77,68,69,70,71,72,73,74,7	79FS+10 days
79	**Design Review Meeting - Liquid**	78FS+10 days	131
80	**Task 3A: 60% Design Solids**		
81	**Plans and Specifications**		
82	Solids Handling Facility	37	88
83	Primary Digester Rehab	37	88
84	Secondary Digesters	37	88
85	CHP System	37	88
86	Yard Piping	37	88
87	Building Refurb	37	88
88	**Submit 60% Design - Solids**	87,82,83,84,85,86	89FS+5 days,112FS-30 days,11
89	**Design Review Meeting - Solids**	88FS+5 days	92,93,94,95,96,97
90	**Task 3B: 90% Design Solids**		
91	**Plans and Specifications**		
92	Solids Handling Facility	89	98
93	Primary Digester Rehab	89	98

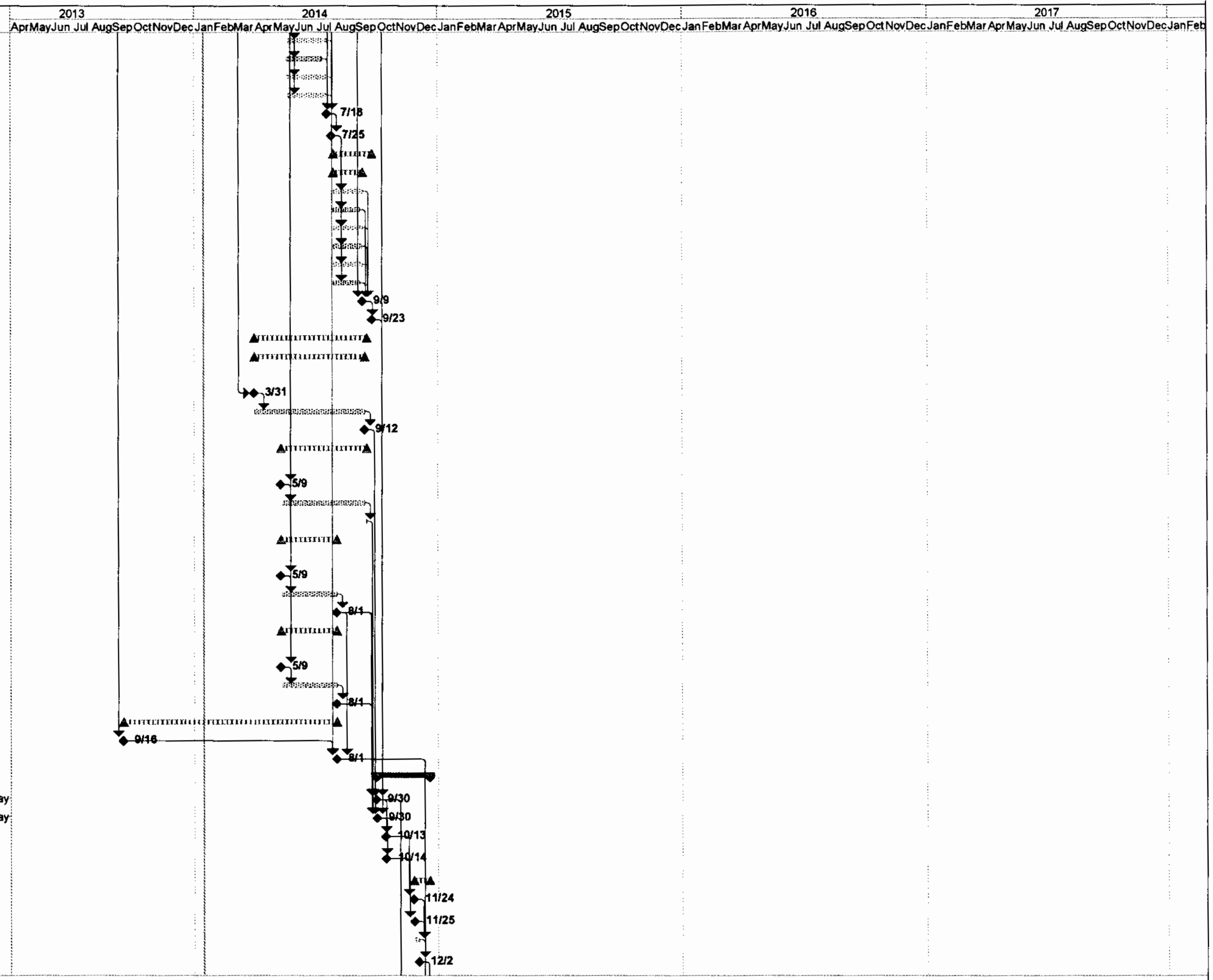


CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP

Task	Project Summary	Inactive Task	Duration-only	Finish-only	Deadline
Split	External Tasks	Inactive Milestone	Manual Summary Rollup	Critical	
Milestone	External Milestone	Inactive Summary	Manual Summary	Critical Split	
Summary	Inactive Task	Manual Task	Start-only	Progress	

IMPROVEMENTS TO THE FRITZ ISLAND WWTP

ID	Task Name	Predecessors	Successors
94	Secondary Digesters	89	98
95	CHP System	89	98
96	Yard Piping	89	98
97	Building Refurb	89	98
98	Submit 90% Design - Solids	97,92,93,94,95,96	99FS+5 days
99	Design Review Meeting - Solids	98FS+5 days	102,103,104,105,106,107
100	**Task 3C: 100% Design Solids**		
101	**Plans and Specifications**		
102	Solids Handling Facility	99	108
103	Primary Digester Rehab	99	108
104	Secondary Digesters	99	108
105	CHP System	99	108
106	Yard Piping	99	108
107	Building Refurb	99	108
108	Submit 100% Design - Solids	107,102,103,104,105,106,	109FS+10 days
109	Design Review Meeting - Solids	108FS+10 days	132FS+5 days
110	**Permitting**		
111	**DEP Part II and DRBC Permit Applications (both contracts)**		
112	Permit Application	50FS-30 days,88FS-30 da	113
113	Permit Review	112	114
114	Permit Issued	113	131,132
115	**Chap 105/106 Permit Application (both contracts)**		
116	Permit Application	50,88	117
117	Permit Review	116	118
118	Permit Issued	117	131,132
119	**E&S / General NPDES Permits (both contracts)**		
120	Permit Application	50,88	121
121	Permit Review	120	122
122	Permit Issued	121	131,132,129
123	**City of Reading Land Development Plan (both contracts)**		
124	Plan Submission	50,88	125
125	Plan Review	124	126
126	Plan Approved	125	131,132
127	**PENNVEST**		
128	Preapplication Meeting	5	129
129	Application Approval	37,128,122	140
130	***TASK 4: PROJECT BIDDING PHASE***		
131	***Bid Ready Documents - Liquid***	114,118,122,126,79	133FS+10 days,143FS+30 day
132	***Bid Ready Documents - Solids***	109FS+5 days,114,118,12	134FS+10 days,143FS+30 day
133	**Task 4D: Pre-Bid Meeting - Liquid**	131FS+10 days	136FS+30 days
134	**Task 4D: Pre-Bid Meeting - Solids**	132FS+10 days	137FS+30 days
135	**Task 4F: Project Award**		
136	Bid-Opening - Liquid	133FS+30 days	138
137	Bid-Opening - Solids	134FS+30 days	138
138	Tabulate Bids	137,136	139
139	Bid Evaluation	138	140FS+12 days

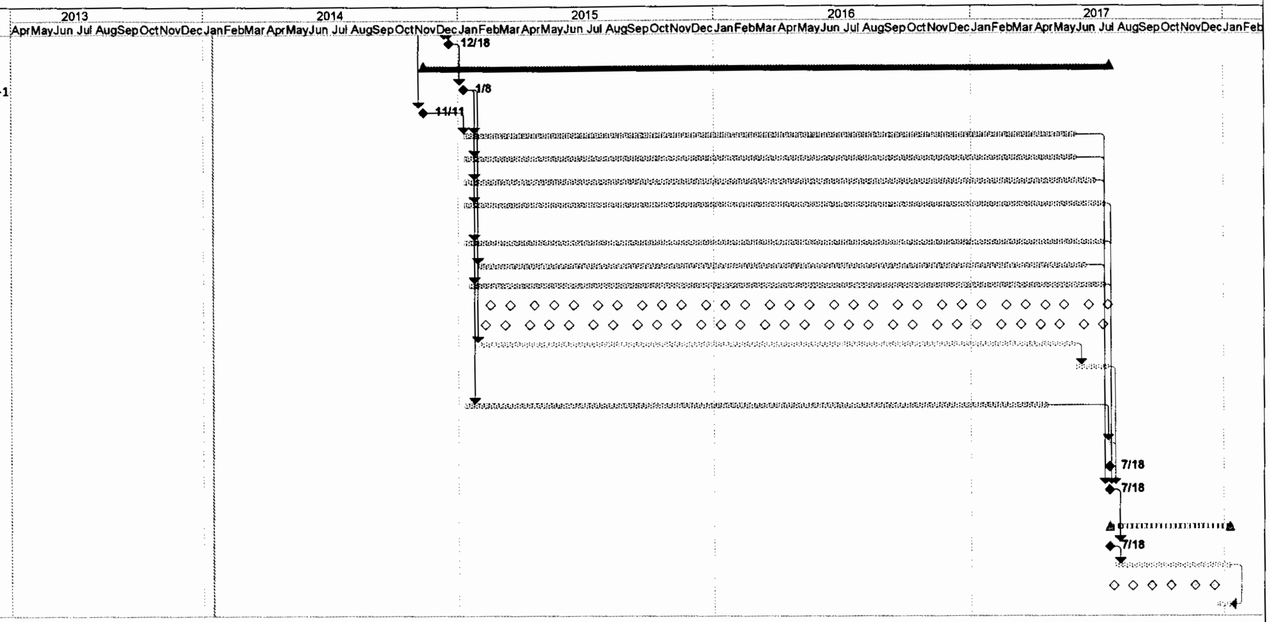


CITY OF READING
IMPROVEMENTS TO THE FRITZ ISLAND WWTP

Task	Project Summary	Inactive Task	Duration-only	Finish-only	Deadline
Split	External Tasks	Inactive Milestone	Manual Summary Rollup	Critical	
Milestone	External Milestone	Inactive Summary	Manual Summary	Critical Split	
Summary	Inactive Task	Manual Task	Start-only	Progress	

IMPROVEMENTS TO THE FRITZ ISLAND WWTP

ID	Task Name	Predecessors	Successors
140	***Award Contracts***	139FS+12 days,129	142FS+15 days
141	***TASK 5: CONSTRUCTION***		
142	Pre-Construction Meeting	140FS+15 days	144,145,148,146,147,149FS+1
143	**Task 5A: Conformed Contract Documents**	131FS+30 days,132FS+30	144
144	**Task 5B: Shop Drawings**	142,143	218
145	**Task 5C: Shop Drawing Log**	142	218
146	**Task 5D: Requests for Information**	142	218
147	**Task 5E: Evaluations of Contractor Substitutions or Deviations**	142	218
148	**Task 5F: Recommendations for Payment**	142	218
149	**Task 5G: Change Orders**	142FS+14 days	218
150	**Task 5H: Supplemental Information**	142FS+5 days	218
151	**Task 5I: Progress Meetings**	**142**	**216**
182	**Task 5J: Site Visits**		
213	**Task 5K: Witness Shop Testing**	142FS+14 days	214
214	**Task 5L: Substantial Completion / Punchlist**	210,213	218
215	**Task 5M: O&M Manuals and Record Drawings**	142	216
216	**Task 5N: Walk Through**	215,151	218,223
217	**Task 5O: Construction Administration**		
218	***Issue Certificate of Final Completion***	216,181,212,214,144,145,	220,222
219	***TASK 6: POST-CONSTRUCTION***		
220	***Construction Complete***	***218***	***221FS+5 days***
221	**Task 6A: Start-up**	220FS+5 days	229FF
222	**Task 6B: Training Sessions**	**218**	**229**
229	**Task 6C: Contract Closeout Report**	221FF,222,228	



CITY OF READING IMPROVEMENTS TO THE FRITZ ISLAND WWTP	Task	Project Summary	Inactive Task	Duration-only	Finish-only	Deadline
	Split	External Tasks	Inactive Milestone	Manual Summary Rollup	Critical	
	Milestone	External Milestone	Inactive Summary	Manual Summary	Critical Split	
	Summary	Inactive Task	Manual Task	Start-only	Progress	